CALIFORNIA
ENERGY
COMMISSION

2004 Annual Review of the PIER Program Volume 8 – Energy Innovations Small Grants Program Project Summaries

STAFF REPORT

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A New Physical Water Treatment Technology for Energy-Efficient Water-Cooled Air-Conditioning Systems

EISG Grant Number: 03-11
PIER Area: Building End-Use Efficiency
Principal Investigator: Wontae Kim (610) 935-8170
Organization: Choson Research Corp.
Grant Amount: $74,290
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using strong pulsating electric fields with inert electrodes placed directly into the circulating water in water-cooled air conditioning systems to achieve a reduction in mineral and bio fouling in the condenser tubes such that chemical treatment is no longer needed.

Proposed Outcome:
- A prototype will be fabricated and tested.

Anticipated Benefits:
- Potential to significantly reduce environmental damage caused by anti bio-fouling and scale inhibiting chemicals used in 92% of the facilities that have water cooled air conditioning systems.
- Potential to increase the heat transfer efficiency of cooling towers by 10% over current state of the art physical water treatment methods which could reduce total California energy consumption by 6-9 GWh per year or approximately 2-4%.

Project Status:
- Detail cell package design – 100%.
- Fabrication of prototype cell packages – 35%.
- Testing of prototype cell package – 0%.
- Perform a manufacturing cost analysis of the proposal cell package – 0%.

A Unique Dielectric Light Injector for Ultra Efficient Photovoltaic Cavity Converters: A Novel Approach for Advanced Solar Concentrators and Directed Laser Power Beam Applications

EISG Grant Number: 03-27
PIER Area: Renewable Energy Technologies
Principal Investigator: Ugur Ortabasi (760) 761-0463
Organization: United Innovations, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of designing, fabricating, and testing a novel Dielectric Light Injector for highly efficient collection, transmission and extraction of concentrated solar radiation into a small spherical space.

Proposed Outcome:
- A Dielectric Light Injector will be fabricated and tested.

Anticipated Benefits:
- May achieve solar-to-electric system efficiencies equal to or over 50% corresponding to a full system efficiency of over 38%.
- Potential to have an installed system cost of $2.50 / watt in the near term.
- Proposed system has the potential to generate power at $.03/kWh, which is competitive with central grid power.

Project Status:
- Projected Start date October 1, 2004.
- First progress report due no later than 4 months after start date.

A Zero Current Ripple, Energy Efficient, and Reliable Low Cost Residential and Commercial Zero Emissions Direct Power-Conversion System

EISG Grant Number: 03-12
PIER Area: Renewable Energy Technologies
Principal Investigator: Sudip Kumar Mazumder (312) 355-1315
Organization: University of Illinois
Grant Amount: $74,999
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of a new inverter design for fuel cells and photovoltaic (PV) systems that would reduce cost, increase reliability and increase conversion efficiency.

Proposed Outcome:
- A 5 kilowatt (kW) prototype will be fabricated and tested.

Anticipated Benefits:
- Potential to achieve the Department of Energy power electronics cost target of $40/kW capacity for fuel cells and PV systems.
- Potential to increase inverter efficiency by 2.5% for single-phase and 3.5% for three phase outputs.

Project Status:
- First progress report in progress.

Biomass-to-Syngas, Novel Low-Cost Counter-Current Process

EISG Grant Number: 03-17
PIER Area: Renewable Energy Technologies
Principal Investigator: Donald Taylor (714) 832-9526
Organization: Individual
Grant Amount: $74,908
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a novel biomass-to-syngas process specifically designed for low-cost conversion of biomass into high-quality syngas suitable for use in solid-oxide fuel cells for power generation.

Proposed Outcome:
- A bench-scale system will be fabricated and tested.

Anticipated Benefits:
- The proposed technology could provide the needed conversion technology to utilize the estimated 100,000 tons per day of biomass available in California. Biomass is a renewable resource for power generation.
- One ton per hour, farm-scale biomass systems producing 1,723 kilowatt hours (kWh) at a cost of $0.10/kWh.

Project Status:
- Finalize design of test reactor – 100%.
- Fabricate 1 million British thermal units per hour (MM Btu/hr) test reactor – 100%.
- Fabricate test-stand and install test equipment – 100%.
- Test plan approval – 0%.
- Conduct testing – 70%.
- Document operation – 70%.
- Collect and reduce data – 50%.
- Project pilot-scale performance – 90%.
- Extrapolate data to large-scale operation – 90%.
- Complete PDU preliminary design – 90%.
- Complete cost projections – 90%.
- Final Report – 20%.

Biosolar Conversion of Carbon Dioxide into Hydrogen Via Bacteria Embedded in Colloidal Gas Aphrons

EISG Grant Number: 03-29
PIER Area: Energy Systems Integration
Principal Investigator: Laurent G. Pilon (310) 206-5598
Organization: University of California, Los Angeles
Grant Amount: $74,948
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing an inexpensive, efficient, scalable, autonomous and reliable system for producing hydrogen from microbial consumption of carbon dioxide. The proposed method is growing photosynthetic bacteria in colloidal gas aphrons to produce hydrogen gas.

Proposed Outcome:
- A prototype will be fabricated and tested.

Anticipated Benefits:
- Potential to reduce carbon dioxide (CO_2) emission from fossil-fueled electricity generation units by 25%.
- Proposed technology may produce hydrogen in a sustainable and environmentally friendly manner.

Project Status:
- Projected Start date October 1, 2004.
- First progress report due no later than 4 months after start date.

Covell Village – A Model for Sustainable Communities

EISG Grant Number: 03-10
PIER Area: Energy Systems Integration
Principal Investigator: Mark Berman (530) 753-1100
Organization: Davis Energy Group, Inc.
Grant Amount: $74,965
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of designing a planned community that incorporates a comprehensive energy plan that reduces energy consumption by 50% based on current Title 24 energy standards. The plan would incorporate energy efficient building construction, renewable energy sources, distributed co-generation, and district heating and cooling strategies.

Proposed Outcome:

- This project will result in a master energy plan for the planned community.

Anticipated Benefits:

- Potential to decrease electrical consumption by 50% compared to equivalent houses built to current Title 24 standards.
- Potential to decrease gas consumption by 50% compared to equivalent houses built to Title 24 standards.
- Potential to reduce CO_2 emissions by 40% or more compared to conventional housing developments.

Project Status:

- Evaluate energy needs – 100%.
- Forecast energy supply/demand thru 2020 – 80%.
- Evaluate renewable energy resources – 70%.
- Evaluate district heating and cooling – 80%.
- Evaluate costs and economics – 80%.
- Identify business, code and regulatory issues – 90%.

Development of a Wireless Lighting Control Network

EISG Grant Number: 03-23
PIER Area: Building End-Use Efficiency
Principal Investigator: Charlie Huizenga (510) 643-8003
Organization: University of California, Berkeley
Grant Amount: $74,915
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing and demonstrating a wireless lighting control system based on miniature low-power radio network technology currently being developed at UC Berkeley. The system will be appropriate for both retrofit and new construction.

Proposed Outcome:
- A control system will be developed and tested.

Anticipated Benefits:
- Potential to provide an automated method of turning off lights in unoccupied work areas.
- Potential to automatically shed 50% or more of the lighting load in buildings where the system is installed during peak periods without compromising health and safety.
- The proposed lighting control is applicable to exiting buildings as a retrofit. It would not require replacing existing fluorescent ballasts or fixtures and the control could be installed in a fixture in a few minutes.

Project Status:
- Projected Start date October 1, 2004.
- First progress report due no later than 4 months after start date.

Efficient Lighting by Sensing and Actuating with MEMS 'Smart Dust Motes'

EISG Grant Number: 03-20
PIER Area: Building End-Use Efficiency
Principal Investigator: Alice Agogino (510) 642-6450
Organization: University of California, Berkeley
Grant Amount: $74,009
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing and testing 'Smart Dust Motes' for sensing, actuating and personalizing dimmable fluorescent lighting systems.

Proposed Outcome:
- 'Smart Dust Motes' will be fabricated and tested.

Anticipated Benefits:
- Potential to reduce the cost of retrofitting dimmable fluorescent lighting as part of a central energy management strategy.
- Provides demand-responsive control algorithms that balance conflicting occupant needs with the desires of the building manager.
- Provides for personal optimization to increase user acceptance.

Project Status:
- Projected start date October 1, 2004.
- First progress report due no later than 4 months after start date.

High Efficiency Lanthanide Doped Ceria-Zirconia Layered Hybrid Electrode for SOFC Generators

EISG Grant Number: 03-14
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Juan L. Sepulveda (520) 295-4611
Organization: Intertec Advanced Materials, Inc.
Grant Amount: $74,936
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of increasing the efficiency of Solid Oxide Fuel Cells (SOFC) by unique design and application of ceria to zirconia to form an improved solid electrolyte.

Proposed Outcome:
- Electrolyte and electrode formulations will be fabricated and tested.

Anticipated Benefits:
- Potential to provide energy at a cost estimated to be around $0.039/kWh, roughly a 5% cost reduction from the current state of the art.
- The proposed improved fuel cell technology may provide the following advantages: reduced emissions, higher efficiency, co-generation capability, enhanced grid reliability and elimination of transmission losses.

Project Status:
- Set up detailed work plan – 100%.
- Develop electrolyte and electrode formulations – 95%.
- Fabricate electrolyte – 90%.
- Fabricate electrode – 50%.
- Test cell manufacturing and testing – 35%.
- Manufacturing cost analysis – 0%.
- Conduct life cycle cost analysis – 0%.

High-Performance, Nanostructured Cathode for Li-ion Rechargeable Battery

EISG Grant Number: 03-28
PIER Area: Energy Systems Integration
Principal Investigator: Ning Pan (530) 752-6232
Organization: University of California at Davis
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing a novel nanostructured lithium-cobalt dioxide ($LiCoO_2$) cathode for a Li-ion rechargeable battery with high-capacity and high-rate capability, by using the electrophoretic deposition (EPD) method for low-cost production.

Proposed Outcome:
- Cathode films will be fabricated and characterized by electrophoretic deposition (EPD).

Anticipated Benefits:
- Potential to increase the capacity of rechargeable batteries by over 50% and reduce the cost of rechargeable batteries by 30%. Thus the cost-efficiency of the projected lithium-ion rechargeable power system will increase over 80%.
- Eliminates toxic materials in battery construction with environmentally friendly materials.
- Potential to provide large scale energy storage capability at a lower cost.

Project Status:
- Projected start date October 1, 2004.
- First progress report due no later than 4 months after start date.

Innovative Injection-Molded Plastic for High-Concentration PV Cells

EISG Grant Number: 03-16
PIER Area: Renewable Energy Technologies
Principal Investigator: Kenneth W. Stone (310) 325-8091
Organization: Amonix
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of using a new injection-molded thermal plastic in the manufacture of modules that hold solar cells in high-concentration solar-cell systems, thereby reducing the manufacturing costs of these modules.

Proposed Outcome:
- A prototype cell package will be fabricated and tested.

Anticipated Benefits:
- Potential to lower the installed cost/watt of a high concentration PV system by more than 15%.
- Proposed concept could be used to mount the next generation multi-junction high-concentration solar cells that are currently under development, which could result in a 30% reduction in installed cost/watt.

Project Status:
- Cell package detail design – 100%.
- Fabrication of prototype cell packages – 35%.
- Testing of prototype cell package – 0%.
- Perform a manufacturing cost analysis of the proposal cell package – 0%.

Innovative Wheel Concept to Increase Gas Turbine Efficiency

EISG Grant Number: 03-15
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Mark J. Skowronski (714) 317-5016
Organization: Markron Technologies LLC.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of increasing the efficiency of small Brayton-cycle gas turbines by using nozzles on the periphery of a bladeless turbine wheel to reduce wheel losses.

Proposed Outcome:
- A prototype will be fabricated and tested.

Anticipated Benefits:
- If successful and full market penetration in the 1-3 megawatt (MW) range was achieved the annual benefit to California would be the reduction of 45 tons of nitrogen oxides (NO_x), 59,000 tons of methane (CH_4), and over 60,000 tons of carbon dioxide (CO_2) emissions.
- Potential to provide a small gas turbine design for base load power generation capable of producing power at $.05/kilowatt hour (kWh) based on lifecycle costs.
- Potential to produce an estimated $16 million annually in energy and capacity reductions due to the higher efficiencies achieved with the proposed technology, based on a 5-year market penetration of 250 megawatts.

Project Status:
- Develop specifications and design for nozzles and nozzle assembly – 75%.
- Develop specification and design for test wheel and wheel assembly – 75%.
- Develop design for testing rig – 75%.
- Fabrication of wheel and nozzles – 0%.
- Conduct assembly and balancing – 0%.
- Fabricate testing rig – 30%.
- Conduct prototype testing – 0%.
- Upon failure, conduct failure analysis, modify design, and redo testing (if necessary) – 0%.
- Perform Brayton cycle total system performance projections – 20%.
- Conduct life cycle cost analysis – 20%.

New Membrane Based on Ionic Liquids for High Temperature PEM Fuel Cells

EISG Grant Number: 03-19
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Jun John Xu (732) 445-5606
Organization: Rutgers University
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of a new acid/ionic liquid/polymer composite membrane for anhydrous proton conduction in PEM Fuel cells at 150 degrees Celsius.

Proposed Outcome:
- Membrane-electrode-assemblies (MEA) will be fabricated and tested.

Anticipated Benefits:
- May allow the operation of PEM fuel cells at 150°C instead of the current 80°C allowing for easier thermal management, size reduction of heat exchangers, and greater carbon monoxide (CO) tolerance in fuel cell power systems.
- Potential to reduce the cost of PEM fuel cell membranes to less than $100/m2, which is significantly lower than that of Niafion™ ($500-1000/m2) the current state-of-the-art.

Project Status:
- First progress report in progress.

Phase-Change Frame Walls (PCFWs) for Peak Demand Reduction, Load Shifting, and Energy Conservation in California

EISG Grant Number: 03-25
PIER Area: Building End-Use Efficiency
Principal Investigator: Mario A. Medina (785) 864-3604
Organization: University of Kansas
Grant Amount: $74,596
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing an optimized phase-change structural insulated panels that may reduce peak load air conditioning demand and provide energy savings. The panels will be fully characterized in terms of R-values, demand reduction potential, and thermal storage capabilities.

Proposed Outcome:
- Two sets of phase-change frame walls will be fabricated and tested.

Anticipated Benefits:
- Potential to lower air conditioning demand by at least 20%.
- Potential to reduce wall peak heat flux by as much as 42%.

Project Status:
- Projected start date October 1, 2004.
- First progress report due no later than 4 months after start date.

Printed Photovoltaic Images for Roofing

EISG Grant Number: 03-22
PIER Area: Renewable Energy Technologies
Principal Investigator: Russell Gaudiana (978) 569-1410
Organization: Konarka Technologies, Inc.
Grant Amount: $74,482
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing a method for printing patterns on low-cost thin-film dye-sensitized titania photovoltaics (PV) that matches conventional roofing materials to achieve an aesthetically pleasing appearance.

Proposed Outcome:
- Roofing material images will be printed using PV dyes and modules will be fabricated and tested.

Anticipated Benefits:
- Potential to deliver photovoltaics at ~$1/watt at full volume production.
- Potential to achieve an installed cost of $3,000/kilowatt (kW) assuming $1,000/kW PV and $2,000/kW for BOS and installation. This is half the cost per kilowatt hour (kWh) of current PV products.

Project Status:
- Projected start date October 1, 2004.
- First progress report due no later than 4 months after start date.

Pulsed Ultrasound Water Treatment

EISG Grant Number: 03-21
PIER Area: Industrial/Agriculture/Water End-Use Efficiency
Principal Investigator: Robert W. Cribbs (916) 941-7600
Organization: Sonipulse, Inc.
Grant Amount: $74,610
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using pulsed ultrasound to replace chlorine or chlorine compounds, ozone, ultraviolet, peroxide, or other chemical processes to process both municipal water and industrial or agricultural wastewater before discharging it into rivers.

Proposed Outcome:
- A prototype ultrasonic processor will be built and evaluated.

Anticipated Benefits:
- Potential to achieve 99.9% sterilization in seconds rather than minutes or hours.
- Potential to provide an alternative method for water treatment without the negative environmental and health impacts of current technologies.

Project Status:
- Projected start date October 1, 2004.
- First progress report due no later than 4 months after start date.

Test and Evaluation of Heat Transfer Parameters for CAES Tank System

EISG Grant Number: 03-24
PIER Area: Renewable Energy Technologies
Principal Investigator: Paul Lieberman (310) 371-2198
Organization: Lieberman Research Associates
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using 3% by volume of anti-freeze filled copper tubing in the storage tanks of a CAES (tank) system to assure that the temperature swing and pressure swing are acceptable as inputs to the effective operation of a turboexpander.

Proposed Outcome:
- A scaled prototype will be fabricated and tested.

Anticipated Benefit:
- The system has the potential to provide cost effective energy storage for wind farm applications as well as possible industry applications.
- Compared to batteries, the proposed system offers the potential of greater energy storage capacity and longer life (20 years compared to 5 years for batteries). Also, there would be no need to purchase, maintain, and dispose of toxic and corrosive chemicals.
- When incorporated into a wind farm operation the cost of power from the CAES is projected at $.07/kilowatt hour which is competitive.

Project Status:
- Projected start date October 1, 2004.
- First progress report due no later than 4 months after start date.

The DaySwitch

EISG Grant Number: 03-13
PIER Area: Building End-Use Efficiency
Principal Investigator: Peter Morante (518) 687-7100
Organization: Rensselaer Lighting Research Center
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of developing an inexpensive, easy to install, self-commissioning photosensor that will clip into existing lighting fixtures and allow them to automatically shut off lights when sufficient daylight is available.

Proposed Outcome:
- A prototype will be developed and tested.

Anticipated Benefits:
- Potential to provide 30% or more lighting energy reduction in spaces where daylight is present. The total component cost of the photosensor is proposed at less than $6.00.
- Potential to reduce lighting energy consumption in the state by 2.5 billion kilowatt hours (kWh) per year. This would save over $244 million per year for electric ratepayers.
- Potential to reduce peak electric demand in California.

Project Status:
- Product design – 50%.
- Component development and testing – 10%.
- Bench-scale prototype development and testing – 0%.
- Final prototype development and presentation – 0%.

The Mamikon Spinner

EISG Grant Number: 03-26
PIER Area: Renewable Energy Technologies
Principal Investigator: Todd E. Mills (626) 308-4400
Organization: Hi-Q Products, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of fabricating a more efficient blade design for small wind turbines. The new design is a single continuous ribbon shaped into a spinner with spokes to a central hub.

Proposed Outcome:
- A prototype will be fabricated and tested.

Anticipated Benefits:
- Potential to reduce the manufacturing cost by 15-20% compared to conventional turbine blades.
- Proposed concept has the potential to increase the efficiency of small turbines by 7-14% in low wind sites of 12.5-16.8 mph.
- Proposed design has the potential of being more aesthetically pleasing compared to turbines with conventional blades.

Project Status:
- Projected start date October 1, 2004.
- First progress report due no later than 4 months after start date.

EISG Active Projects from Previous Years

A Low-NO_x Porous Ceramics Burner Performance Study

EISG Grant Number: 02-14
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Pei-feng Hsu (321) 674-7246
Organization: Florida Institute of Technology
Grant Amount: $74,988
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a multi-layer cylindrical porous ceramic burner to achieve stable combustion. The emissions and heat release performance of the new porous ceramics burner will be examined in a laboratory environment. Economic analysis of the operation and related cost will be conducted and compared with the existing low NO_x burners, for example, the radiant surface burners made with ceramic fiber mats. It is expected that this study will provide valuable information about the design and operation of porous radiant burners and lead the way to prototype development and demonstration in a future effort.

Proposed Outcome:
- A porous ceramic burner will be fabricated with R-type thermocouples embedded at the interfaces of different porosity ceramics. A radiance measurement system will be constructed.

Anticipated Benefit:
- Potential to increase the efficiency and reduce the NO_x emissions from boilers used for power generation in California.

Project Status:
- Construction of bench-top burner and calibration – 80%.
- Construction of radiance measurement system – 100%.
- Measurement of burner emissions – 60%.
- Measurement of radiant heat flux output – 100%.
- Economic analysis – 0%.

A Novel Integrated Doubly-Fed Electric Alternator/Active Filter (IDEA) for Wind Power Applications

EISG Grant Number: 02-27
PIER Area: Renewables
Principal Investigator: Hamid Toliyat (979) 862-3032
Organization: Texas A&M University
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of integrating a low-cost active filter for power factor correction into the power electronics that control Doubly-Fed Electric Alternators used on state-of-the-art variable speed wind turbines.

The proposed technology will be tested on a 7.5 hp laboratory modeled wind turbine equipped with the proposed IDEA. The advantages of the proposed approach are:

- Adjustable speed control of the wind turbine in order to capture maximum wind energy.
- Compensation of the harmonics in the grid and maintaining the total harmonic distortion (THD) of the grid within the acceptable rang according to IEEE 519 standard.
- Improving the power factor and reactive power control and totally improving power quality.
- The approach is rugged and can be adapted to low and medium voltage systems.
- The system can be controlled to simultaneously generate active green power, compensate for the reactive power and harmonics generated by the nonlinear loads in an industrial, agricultural, and water plant.

Proposed Outcome:

- A prototype system will be fabricated and tested as part of the project.

Anticipated Benefits:

- Potential to reduce the life cycle cost of power generated from adjustable speed wind turbine systems by improving the power quality output from double-fed induction generators, which provide the lowest cost power electronics solution.
- Potential to improve the grid power quality in locations that have grid tied wind turbines.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Initiated.

A PCM Slurry System to Decrease Peak Air Conditioning Loads

EISG Grant Number: 00-19
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Randy Clarksean
Organization: Leading Technology Designs, Inc.
Grant Amount: $73,457
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a phase change material (PCM) mixture to be used in an air conditioning (A/C) unit to absorb peak A/C loads. The slurry is a mixture of water, emulsifier and paraffin. The innovations pursued here are the development of a high concentration PCM Slurry and the development of a low-cost system to absorb A/C loads and to reject that energy to the earth. The project goal is to produce stable, high-volume fraction PCM slurry and demonstrate that this slurry can be pumped through a heat exchanger and stored.

Proposed Outcomes:
- Develop and demonstrate a PCM slurry mixture capable of absorbing 30% or greater of the peak A/C load.
- Fabricate bench-scale PCM system and perform system tests.

Anticipated Benefits:
- A system capable of reducing A/C loads by 30% or more.
- A unit with a production cost range of $40-$160 per kilowatt for heating.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Under Review.

Actively Controlled Jet Injection in Gas Turbine Engine

EISG Grant Number: 99-11
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Ann Karagozian (310) 825-5653
Organization: University of California, Los Angeles
Grant Amount: $74,899
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using actively controlled dilution air jets that deliver pulsed air perpendicular to the intake air flow in the primary zone of a gas turbine's burner to rapidly produce a lean mixture. Dilution air jets are used in gas turbines for temperature control and the reduction of nitrogen oxides (NO_x) through air-fuel mixture ratio control. This project builds upon prior work that modeled pulsed transverse jet flow, and will develop control strategies based on simulations followed by experimental validation using a bench-scale combustor.

Proposed Outcomes:
- Optimal open- and closed-loop control strategies for pulsed transverse dilution jets to achieve maximum reduction of NO_x emissions.
- Combustor design specifications for incorporating pulsed air jets, actuators and sensors.

Anticipated Benefit:
- Reduce NO_x emissions in gas turbines 50% by maintaining a constant, lean air-fuel mixture.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Draft – Under Review.

Advanced Generation of H_2 and CO from Improved Methane-Carbon Dioxide-Steam Reforming Process, for use as Fuel and Methanol, Gasoline Synthesis Gas

EISG Grant Number: 00-32
PIER Area: Energy Systems Integration
Principal Investigator: Zoe Ziaka (818) 893-4292
Organization: Zoe Ziaka
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a catalysis reaction to convert waste gas streams containing carbon dioxide (CO_2) and methane to carbon monoxide and hydrogen, of which the hydrogen could be used to power fuel cells. This technology will utilize and upgrade methane streams that contain CO_2 such as landfill, sour and waste type gases. CO_2 innovative abatement processes, especially within in-situ reactors via relevant reactions and catalysis systems, are under increased consideration in current and future industrial efforts, and are considered an additional benefit of this proposed work. This project will develop a new, effective reforming and catalysis system that converts the above feedstocks and delivers purified grade gas required for fuel cell applications.

Proposed Outcomes:
- Developed selective catalyst.
- Production of synthesis gas from reforming of secondary and waste hydrocarbon streams.
- Completed evaluation of the process for integration to turbines, fuel cells or synthesis gas.

Anticipated Benefits:
- Increased production of Hydrogen.
- Projected energy savings in the range of 20-30%.
- Abatement of CO_2 mixtures, which lowers greenhouse gas emissions.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

AGF Pasteurization Process Assessment, Orange County, CA

EISG Grant Number: 00-03
PIER Area: Renewables
Principal Investigator: Dennis Burke (360) 923-2000
Organization: Cyclus Envirosystems, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a pilot plant using an anoxic gas flotation pasteurization process to more efficiently convert organic materials such as agricultural waste, sewage sludge, and manure into fuel gas and Class A residual solids. The innovative process can use the heat recovered from power generation to increase the quantity of organic material converted to gas while producing disinfected nutrient-rich residual. The capital and operating costs of waste treatment and power generation is lowered while more gas is produced, public health is protected, and disposal of residual solids is reduced.

The biochemical process is the anoxic gas flotation (AGF) pasteurization process that utilizes high temperature waste heat from a turbine, microturbine, or engine generator set to increase the rate and quantity of organic material converted to gas. A 40% improvement in solids converted to gas has been shown at the laboratory bench scale. The AGF pasteurization process also reduces both the amount of process energy required when compared to conventional or thermophilic digestion processes, and the disposed quantity of the concentrated, nutrient rich, residual product. The disinfected residual product can be given or sold to the general public, locally, without restriction.

Proposed Outcomes:
- Pilot plant capable of processing 400 gpd of sewage sludge.
- Optimized methodology for operating processing plant.
- Feasibility analysis based on pilot plant performance.

Anticipated Benefits:
- Up to 40% increase in conversion rate of organic solids to biogas.
- Increase fuel gas production by 25%.
- Reduce solids processing costs by 60%.
- Produce a disinfected Class A residual product that does not require landfill disposal.

Project Status:
- Design – 100%.
- Pilot Plant Construction – 100%.
- Start-up and Initial Operation – 80%.
- Monitoring and Analysis of Process – 50%.
- Evaluation of Process Performance – 0%.

Agripower-Renewable Generation

Agricultural Waste & Forest-Thinnings-To-Energy
EISG Grant Number: 01-10
PIER Area: Renewables
Principal Investigator: Harvey F. Brush (916) 261-2981
Organization: PMC Biomass, LLC
Grant Amount: $74,605
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a new biomass combustion turbine that uses an open Brayton Cycle and modular design called Agripower. This project will perform component and system testing with particular emphasis on the fuel feed and fluidized bed combustion control system. Farms and orchards generate nearly 8 million dry tons of agricultural waste each year and use about 175 trillion British thermal unit's (Btu) annually. These biomass wastes represent some 120 trillion Btu's that could take the place of natural gas in generating process heat or electricity. Specific goals of the Agripower unit are to:

- Utilize in-woods waste as a fuel while reducing or eliminating transportation costs.
- Create energy (possible 120 trillion Btu's annually just from farms and orchards) from agricultural waste with relief of dependency on the grid for many agricultural industries.

Proposed Outcomes:

- A 200 kilowatt biomass powered prototype generator.
- Computerized control software.
- Feasibility analysis of fuel feed system based on performance of prototype system.

Anticipated Benefits:

- Provide a cost effective and environmentally friendly solution for converting a variety of waste biomass feedstocks into electricity and heat. California produces about 9.8 Mil tons of annual forest, mill and urban wood residue, which is the primary targeted feedstock.
- Projected cost (capital and operating) of power generation is $.06/kilowatt hour without cogeneration. With cogeneration the cost can be further reduced.

Project Status:

- Fuel Feed System – 25%.
- Design and Program Instrumentation, Controller – 48%.

An Innovative Approach to Stabilize the Thermal Conductivity of Air Plasma-Sprayed Thermal Barrier Coatings

EISG Grant Number: 00-22
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Rodney Trice (765) 494-6405
Organization: Purdue University
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of increasing the overall efficiency of land-based turbines via an innovative materials solution employing micro-structurally designed thermal barrier coatings (TBCs). Sintering (i.e. densification of the coating) causes the thermal conductivity of thermal barrier coatings to increase by as much as 100-150% during service, greatly reducing the ability of the thermal coating to protect the underlying structure from temperature extremes. For example, the thermal conductivity of an air plasma-sprayed coating will increase from 1.2 W/m-K to 2.3 W/m-K after 50 hours exposure to 1200°C (2192°F) heat. The end result of an increase in the thermal conductivity of the coating is that the gas turbine must be operated at lower temperatures or more cooling must be provided for the hot components. Either of these results decreases the efficiency of electricity production.

To inhibit sintering, the coating will be altered at the atomic level by changing the chemical properties of the TBC via the addition of select dopants. The basic mechanism for inhibiting sintering is based on the "Space Charge Theory." This theory predicts that added dopants will tend to segregate to grain boundaries to keep the crystal electrically neutral. The effect of the cations (positively charged ions) accumulating at the grain boundaries is to prohibit boundary movement, a necessary condition to keep sintering from occurring. The result is that the microstructure that gives rise to the low thermal conductivity is stable because sintering of the coating is prohibited. The goal is a 100% reduction in the long-term thermal conductivity of these microstructurally designed coatings.

Proposed Outcomes:
- Produce a thermal barrier coating capable of maintaining a thermal conductivity of 1.2 W/m- K over 500 hrs at 1400°C (2552° F).
- Produce colloidal suspensions of 1-mm diameter stabilized zirconia and dopants that can be plasma sprayed without agglomeration.
- Optimize the plasma-spray parameters for each stabilized zirconia/dopant to satisfy the following criteria: (a) a high degree of atomic mixing occurs, (b) 1 mm deposition rates are observed, and (c) coatings contain less than 15% porosity.
- Reduce the amount of sintering that occurs in the coatings by reducing grain growth by 100%.

Anticipated Benefits:
- Increase of combustion temperature by 50°C (122° F).
- An increase in efficiency of 3-4%.
- Increased reliability of the coating.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Submitted.
- Feasibility Analysis Report – Analysis in Progress.

Application Feasibility Study of Gravitational Non-equilibrium Heat Pumps and Heat Engines

EISG Grant Number: 00-21
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Thomas C.B. Smith (441) 223-2432
Organization: Thomas C.B. Smith
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a gravitational heat engine (GHE) where the fundamental operating principle is entirely dependent on at least part of the system never reaching equilibrium. The GHE is a Rankine cycle with one moving part. A comprehensive understanding of GHE properties for the purposes of engineering applications does not yet exist. This project will concentrate on investigating the feasibility of GHEs for electricity generation as a cogenerative engine for extracting energy from any low-grade heat source.

Proposed Outcomes:
- Construct functional prototype.
- Demonstrate system efficiency of between 2-10% converting solar energy to electricity.
- Heat engine fueled by solar and low temperature waste heat.
- Feasibility analysis based on performance of functional prototype.

Anticipated Benefits:
- Unit production cost range of $1500-$7500 per kW for electricity production.
- Unit production cost range of $40-$160 per kW for heating.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

Application of Stochastic Filtering and Control Methodology to the Optimization of Wind Turbine Control Design

EISG Grant Number: 03-01
PIER Area: Renewables
Principal Investigator: A. V. Balakrishnan (310) 825-1594
Organization: University of California, Los Angeles
Grant Amount: $74,993
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of applying stochastic filtering and control theories to the problem of improving energy production and mitigating transient fatigue loads for large-scale wind turbines.

Proposed Outcome:
- A comprehensive nonlinear dynamical system model for large-scale wind turbines will be developed and tested as part of the project.

Anticipated Benefits:
- Potential to reduce the cost of energy for wind-generated electricity by 3-5%.
- The proposed advanced optimal control algorithms have the potential to increase the power captured and prolong the lifetime of wind turbines.

Project Status:
- Modeling and problem formulation – 100%.
- Develop stochastic control system design – 100%.
- Develop MATLAB simulation code – 80%.
- Experiment evaluation – 30%.

Attic and Crawl Space Ventilation Air Heat Exchanger

EISG Grant Number: 99-24
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: G Brown (541) 346-5647
Organization: University of Oregon
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a low-cost air-to-air heat exchanger capable of 50% or greater efficiency for use in residential and small commercial buildings. Utilizing a heat exchanger to temper the air before conditioning it will result in reduced building loads leading to down sizing of the HVAC equipment. It will also reduce energy consumption and electrical demand. The primary problem of current heat exchangers is how to reduce their cost so energy savings can pay back the initial cost of the heat exchanger in a short period of time. One solution to this problem is to exploit underused areas in residential and small commercial buildings – the crawl space or attic – to increase heat exchanger surface area and to use thin film tubes to reduce cost. Existing heat exchangers concentrate on reducing overall size while maintaining efficiency. Competitive heat exchangers are more expensive and include finned-tube, plate, heat pipe, and enthalpy.

Proposed Outcomes:
- Two or more full-scale prototype air-to-air-heat exchanges.
- Hardware connection designs for conventional HVAC equipment.
- Feasibility assessment based on prototype performance testing.

Anticipated Benefits:
- Potential energy savings of 825 GWh/yr in California assuming only 10% and 1% market penetration in the residential and commercial building sector respectively.
- Reduce the installed cost of air-to-air heat exchangers by up to 90%.
- Improve the indoor air quality in modern airtight residential housing by providing a cost effective device for conditioning outside ventilation air.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Feasibility Analysis Report Completed.
- Feasibility Analysis Draft Completed – Under Review.

Automating Window Sunshade Control: Toward the Zero Energy House

EISG Grant Number: 01-28
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Murray Milne (310) 454-7328
Organization: University of California, Los Angeles
Grant Amount: $74,685
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of a new kind of microprocessor controlled thermostat that incorporates outdoor temperature sensors to control automated sunshades that reduce the heat load on air conditioners in the summer. Developing this microprocessor controlled thermostat to control the operation of shading elements on the building envelope is an important step towards creating a Zero Energy Home.

Already on the market, especially in Europe, are various electrically-operable sun-control devices. These include awnings that extend and retract, vertical exterior operable louvers, interior operable draperies and venetian blinds. However, none of them has any type of intelligent controller, similar to the microprocessor controlled thermostat developed in a previous EISG project that could read outdoor temperatures and operate shading devices in order to optimize indoor temperatures.

The project result will be the development of a new microprocessor controlled thermostat, a computer program optimized for the best indoor air-temperature control, data demonstrating the differences between interior or exterior shades, and recommendations regarding the best way to install and control automated sun controls. An added goal will be to try to interest either a thermostat manufacturer or an automated shade manufacturer into adding such a device to their product line.

Proposed Outcome:
- A microprocessor controlled thermostat that can sense both indoor and outdoor temperature will be built, programmed and tested as part of the project.

Anticipated Benefits:
- Potential to reduce residential air-conditioning costs by reducing the solar heat gained through windows.
- May allow the shades to automatically adjust to weather changes without the need of human interaction.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- EISG Program Administrator's Review of Final Report Draft in Process.

Biofiltration Abatement of Landfill Gas Energy Exhaust Pollutants

EISG Grant Number: 01-01
PIER Area: Environmental Area
Principal Investigator: Don Augenstein (650) 856-2850
Organization: Don Augenstein
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a biofiltration strategy to clean the exhaust of an internal combustion engine running on landfill gas. Landfill solid waste will be used as the primary contact medium in the biofiltration system. If this technique proves viable, as expected, laboratory data will be extrapolated to full-scale system performance and costs.

Proposed Outcomes:
- Cost and performance projections will be made based on data obtained.
- Plan for full-scale testing if results from this project are encouraging.

Anticipated Benefit:
- Allow recovery of about 300-500MWe of landfill gas electric generation potential that is now stalled in California due to excessive pollutants in energy equipment emissions.

Project Status:
- Assemble laboratory reactors – 100%.
- Develop analytical techniques for exhaust pollutants of greatest concern – 100%.
- Examine abatement kinetics under various gas flow regimes and biofilter characteristics – 90%.
- Estimate cost for application of full-scale biofiltration – 80%.
- Plan large-scale tests – 75%.

Build and Test a 3 kW Prototype of a Co-Axial, Multi-Rotor Wind Turbine

EISG Grant Number: 02-18
PIER Area: Renewables
Principal Investigator: Douglas Spriggs Selsam (714) 992-5594
Organization: Selsam Innovations
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of a low-cost wind turbine design that incorporates 7 rotors on a horizontal shaft. A 3 kilowatt prototype will be fabricated and tested as part of the project. The new design, now proven in small models, combines the power of multiple smaller rotors mounted to a single elongate driveshaft to give the same power as a single larger rotor with less cost, weight, and complexity. This research will pave the way for more advanced turbines utilizing this new co-axial, multi-rotor technology.

Proposed Outcome:
- A 3 kilowatt prototype will be constructed and tested.

Anticipated Benefits:
- Potential to reduce the footprint of wind turbines while maintaining the same power output, which would allow wind farms to increase their electrical output cost effectively.
- Potential to reduce the cost of wind turbine power by using rotors that are less costly to buy and maintain.

Project Status:
- Build a 3 kilowatt multi-rotor, co-axial turbine – 100%.
- Preliminary testing – 100%.
- Revise prototype for long term testing – 90%.
- Perform long term (6 months) testing – 50%.

Carbon Catalyzed Natural Gas Processing

EISG Grant Number: 02-21
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Steve Chu (612) 877-0765
Organization: Sunnyside Technologies, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of producing both carbon monoxide (CO)-free hydrogen for PEM fuel cells and nanostructured carbon for carbon fuel cells through a precisely controlled chemical processing of natural gas catalyzed by nanostructured carbon resulting in four times the hydrogen gas (H_2) yield of conventional thermal cracking process. This technology eliminates the complex CO removal processes in conventional hydrogen production such as steam reforming and gas shift reaction. Therefore it will increase the hydrogen quality, reduce the production cost, and be more competitive.

Proposed Outcome:
- To correlate the relationship among the process parameters, carbon structures, catalytic activities, and the electrochemical performance as fuel.

Anticipated Benefits:
- Potential to provide high quality hydrogen fuel and carbon fuel from natural gas without the production of the greenhouse gas carbon dioxide (CO_2).
- Potential to provide the correct type of carbon fuel for carbon fuel cells, which are capable of energy efficiencies up to 80%.

Project Status:
- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft in Progress.

Carbon Foam Based NO_x Biofilter

EISG Grant Number: 00-04
PIER Area: Environmental Area
Principal Investigator: Daniel Chang (530) 752-2537
Organization: University of California, Davis
Grant Amount: $74,989
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using Ultramet carbon foam as a packing material in a post combustion nitrogen oxides (NO_x) biofilter to increase efficiency and reduce capital cost. However, biofiltration to control NO_x is difficult because of mass transfer rate limitations. Newly engineered materials developed for other applications, e.g., Ultramet carbon foam for catalyst supports, can be tailored to meet the needs of an inexpensive, light-weight, inert, biofilter packing that provides a high specific surface area (surface-to-volume) to greatly increase the mass transfer rate. University of California, Davis believes that the key to economical biological treatment of NO_x is to maximize the specific surface that can support the necessary biofilm without clogging. The objective of this work is to conduct energy-related environmental research that demonstrates the feasibility of developing a commercially viable NO_x biofilter.

Proposed Outcomes:
- Subscale prototype biofilters.
- Design parameters for system scale up.
- Feasibility analysis based on performance of prototype biofilters.

Anticipated Benefits:
- Reduce the cost of NO_x removal by at least 50% to $0.40/lb-$NO_x$.
- Provide cost effective means of lowering emissions from small-distributed generation units.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Under Review.

Closed Cycle Valved Cell Heat Engine

EISG Grant Number: 00-01
PIER Area: Renewables
Principal Investigator: Joseph Bland (916) 429-6252
Organization: Joseph Bland
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of fabricating a low-cost heat engine that is capable of operating efficiently on low-temperature external heat sources. This project will construct, test and analyze a proof-of-principle prototype of a closed-cycle valved cell engine (VCE). The objectives of the project are to determine if it is technically and economically feasible to fabricate the proposed engine design and to establish that the proposed design is capable of operating effectively from external heat sources in the range of 500-800^{0}F. The VCE is targeted at low temperature heat sources because of its unique ability to deliver very high work output per pound of working fluid (about 50% greater than that of a comparable Stirling engine). The VCE can operate effectively and efficiently at these very low source temperatures. This makes it an ideal heat engine for solar, geothermal and waste heat applications. The VCE's power density also means it can tap efficiently into very small heat sources.

Proposed Outcomes:
- Prototype closed-cycle valved cell engine.
- Feasibility analysis based on prototype performance.

Anticipated Benefits:
- Low-cost heat engine design capable of generating 2-3 kilowatt from concentrated solar or other low temperature sources.
- 0% higher work output per pound of working fluid compared to a Sterling engine.
- Low capital cost with 3-5 year pay back period.
- Zero emissions when operated from solar energy.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Under Review.

Commercial and Residential Super Insulated Phase Change Material Water Heater

EISG Grant Number: 00-18
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Nick Wynne (937) 376-8233
Organization: Regents of the California State Universities
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing an innovative electric water heater that increases operating efficiency by incorporating vacuum insulation and phase change materials. This will be accomplished by means of an innovative advanced technology water heater design that uses the advantages provided by vacuum insulation panel (VIP) and phase change material (PCM) technologies to reduce operating expenses and improve the efficiency of maintaining heated water. Energy stored in heated water statically awaits demand throughout the day and is frequently wasted due to stand-by losses.

The proposed water heater will be designed to optimize the storage of heat in a phase change material (PCM) through which cold water passes to become heated. It will use VIP to retain the heat in the PCM over a long period and be recharged (heated to change phase) during less expensive, off-peak hours for electricity/natural gas. Such a heater will provide more efficient and lower cost hot water. The operating cost will be reduced through off-peak energy savings, reduced stand-by energy losses, and long life.

Proposed Outcomes:
- Full scale prototype hot water heater.
- Feasibility analysis based on performance of prototype system.

Anticipated Benefits:
- Increase the average water heater life from 7 years to 50 years.
- Increase water heater efficiency by 6% by reducing standby losses.
- Provide increased ability to shift energy consumption to off-peak hours.

Project Status:
- Review cost, availability, characteristics of PCM – 100%.
- Review heat exchanger and submersible pump options – 90%.
- Evaluate effectiveness of vacuum panel insulation – 90%.
- Evaluate techniques for circular seals in Vacuum panel insulation – 100%.
- Evaluate improved design, manufacturability of cylindrical vacuum panel insulation – 100%.
- Develop options for installing thermal breaks on water heater protrusions – 100%.
- Benchmark PCM/Heat exchanger combinations – 20%.
- Build prototype – 0%.
- Test prototype – 0%.

Construction and Testing of a High-Efficiency Solar Water Still

EISG Grant Number: 03-07
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Paul LaViolette (703) 256-4887
Organization: The Starburst Foundation
Grant Amount: $74,998
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing a novel multi-effect solar still design that is capable of cost effectively desalinating agricultural drainage water for reuse in crop irrigation.

Proposed Outcome:
- A prototype will be fabricated and tested as part of the project.

Anticipated Benefits:
- Potential to provide significant power savings since the proposed technology consumes only about 500-kilowatt hours per acre-foot of processed water, which is about 7 times less power than reverse osmosis.
- Potential to desalinate drainage water with up to 10,000 total dissolved solids at a cost of $490/AF, which is comparable to reverse osmosis, but with considerably less power consumption and waste brine volume.

Project Status:
- Preparation: Fit up facility; Hire personnel; Procurement activity – 95%.
- Design/Prepare working sketch of prototype 10m2 still. Fabricate polyethylene film version of still – 100%.
- Test polyethylene version of still; modify prototype if necessary – 90%.
- Fabricate PFA canopy – 0%.
- Test PFA canopy – 0%.
- Economic Analysis – 0%.

Controlling Fouling with Rice Straw Blends in Biomass Boilers

EISG Grant Number: 00-20
PIER Area: Renewables
Principal Investigator: Charles E. Lesher
Organization: University of California, Davis
Grant Amount: $73,858
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a test plan that will determine the allowable additions of rice straw to wood-based fuels in order to minimize alkali volatilization and thus to restrict fouling potential. The California biomass power industry is facing increasing environmental and economic pressures to utilize herbaceous fuels, such as rice straw. These fuels are expected to increase the potential for slag deposition and fouling of heat exchangers that lead to a reduction in the efficiency of biomass power generation and to an increase in operating costs. However, new experimental results show that the addition of rice straw to conventional biomass fuel types can reduce alkali volatilization.

The test plan will determine the allowable additions of rice straw to wood-based fuels in order to minimize alkali volatilization and thus restrict fouling potential. The fusion temperatures and rates of potassium volatilization of slag formed from blends of rice straw and wood ashes will be established. These data will be used to formulate predictive models for the high-temperature fouling potential, the physical properties, and tenacity of slag deposits from fuel blends. From the results, practical predictions regarding tolerable fuel blends and proposed new combustion strategies utilizing unconventional and lower-cost blends of herbaceous and conventional wood fuels will be proposed. These predictions will be tested in a fluidized bed combustor.

Proposed Outcomes:
- Quantify fouling potential of rice straw fuel blends.
- Determine optimal rice straw fuel blends for reducing fouling.
- Demonstrate that a minimum addition of 10% rice straw can be accomplished without a proportional increase in fouling rate.

Anticipated Benefits:
- Increased fuel flexibility for fluidized bed combustor.
- Reduced maintenance costs.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Demonstration of Energy Efficient Enhancement in Refrigeration Appliances by Incorporation of Practical, Low Cost Thermal Energy Storage

EISG Grant Number: 02-24
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Timothy James (805) 252-7190
Organization: TES Technology, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of using a novel thermal energy storage design to increase the energy efficiency of refrigeration and cooling appliances. Target refrigeration appliances include domestic appliances (combination or stand alone refrigerators and freezers), notoriously inefficient compact refrigerators (found in hotel rooms, dorm rooms, home bars, etc and now being mass marketed by major retail chains), commercial vending and display cases, domestic and small commercial air conditioning systems, etc. Thermal energy storage (TES), when appropriately incorporated into refrigeration appliances, improves energy efficiency by stabilizing the evaporation temperature and eliminating the inefficient low temperature excursions typical of on/off modulated vapor-compression refrigeration systems. Additional efficiency and other benefits include a narrower operating temperature range and more stable storage temperatures and humidity levels. For vending and display cases, TES can provide reserve capacity for peak cooling loads (e.g., chilling new warm product) thus eliminating the need for a high capacity cooling system with compromised efficiency under steady-state conditions. For small capacity A/C TES can provide stored capacity enabling peak load shifting and interruptible or off-peak power utilization.

Proposed Outcome:
- A prototype system will be fabricated and tested in two refrigerator models.

Anticipated Benefits:
- Potential to reduce residential energy consumption by 95 kWh/year (assumes conventional refrigerators consume 475 kWh/yr and 20% efficiency improvement).
- Potential to save up to 160 GWh/year statewide in just residential refrigerators (assumes 16 million units in California, 475 kWh/yr/unit, 10% market penetration, 20% energy savings).

Project Status:
- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft in progress.

Desiccant Enhanced Indirect/Direct Evaporative Cooling System

EISG Grant Number: 01-22
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: William A. Belding (530) 268-7397
Organization: Innovative Research Enterprises
Grant Amount: $74,900
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of a new air conditioning design that incorporates indirect/direct evaporative cooling and dehumidification with gas regeneration. The proposed indirect/direct system employs desiccant components within the indirect cooling stage, thus simultaneously dehumidifying and cooling the process air. With the proposed technology a single component will perform at improved efficiency the functions now performed by a desiccant dehumidifier and a heat exchanger. Having improved performance over existing techniques, the system can be used as a total cooling solution for western climates and eliminate the need for conventional vapor compression systems.

Proposed Outcome:
- A prototype heat exchanger will be built and tested as part of the project.

Anticipated Benefits:
- System design capable of SEER rating greater than 30 as opposed to traditional vapor compression units, which have a SEER of 10-16.
- Potential to shift some of the peak electrical load used for alternating current (AC) to natural gas.
- May increase comfort and indoor air quality by supplying up to 100% outdoor air to the conditioned space.

Project Status:
- 100% Complete.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report – Analysis in Progress.

Detecting Optimal Fan Pressure

EISG Grant Number: 02-03
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Clifford Federspiel (510) 418-3392
Organization: Federspiel Controls
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a new algorithm for more accurately determining the optimal pressure at which to operate variable air volume (VAV) air-handling systems. This project will involve the testing and demonstration of a new method of detecting the optimal pressure at which to operate variable air volume (VAV) air-handling systems. The ability to detect this pressure will enable VAV systems to use less energy during both on-peak and off-peak periods.

Proposed Outcome:
- A test stand will be fabricated. The test stand will include a computer-based data acquisition system, a supply airflow station and a supply duct pressure sensor.

Anticipated Benefits:
- The proposed algorithm has the potential to enable a reduction in source energy consumption in California of .018 quads. The reduction corresponds to an annual cost savings of $171 million and a reduction in carbon emission of 0.27 million metric tons per year.
- Potential to reduce electrical consumption during peak electrical demand periods.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

Development of a Borehole Seismic Receiver Array for Geothermal Wells

EISG Grant Number: 99-37
PIER Area: Renewables
Principal Investigator: Bjorn Paulsson (562) 694-9598
Organization: Paulsson Geophysical Services
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a borehole seismic receiver array for geothermal wells capable of operating in a temperature range of 200 to 250°C. Existing short- and low-temperature arrays severely limit the use of borehole seismology in geothermal energy exploration. This project will address this shortcoming by developing a much larger seismic receiver array that can operate at much higher temperatures.

This technology will make it possible to routinely map high permeability zones and monitor production in fractured geothermal reservoirs with a resolution in the range of 3 to 6 ft (1 – 2 m) using 3D Vertical Seismic Profile (VSP), passive seismic monitoring and cross-well seismic techniques. Three component arrays allow recording of both P and S wave data that together provide information on the location, the size and the preferred direction of fractures and fracture zones in the reservoir. The fracture information is the key information that will help determine the directional permeability of the reservoir and how to economically produce its geothermal resources.

Proposed Outcomes:
- Cable design capable of withstanding operational temperatures of 200 to 250°C.
- A prototype five-level high-temperature borehole seismic-receiver array.
- Feasibility assessment based on prototype performance testing in a field setting.

Anticipated Benefits:
- Ability to record P and S wave data that enable the mapping of fracture zones in high-temperature geothermal reservoirs.
- Enable more efficient management of existing geothermal reservoirs.
- Reduce the number of wells needed to develop a geothermal resource.
- Allow economic development of lower temperature and lower permeability geothermal fields.

Project Status:
- Project Terminated.
- Project Completed - 25%.
- Final Report Submitted.

Development of a Modular Scroll-Turbine-Based Organic-Ranking Cycle (ORC)

EISG Grant Number: 03-06
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Malick Kane (510) 486-7380
Organization: EnefTech Corporation
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing a 5 kilowatt micro-power generation system based on the organic-Rankine cycle that incorporates a two-stage scroll turbine to reduce cost.

Proposed Outcome:
- A prototype system will be fabricated and tested as part of the project.

Anticipated Benefits:
- The proposed technology could help to satisfy the need for small distributed power generation systems that can operate on waste heat and a variety of renewable heat sources (solar, biomass combustion, landfill gas, etc.).
- Potential to produce electricity at less than 5 cents per kilowatt hour, which is competitive with other generation technologies.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft in progress.

Development of an Effective Fire-Shield for Powerpoles by Custom Tailoring a Mineral Polymer Material

EISG Grant Number: 01-13
PIER Area: Energy Systems Integration
Principal Investigator: Clem Hiel (626) 351-2082
Organization: Composite Support & Solutions, Inc.
Grant Amount: $74,510
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a low-cost fire shield for power poles made out of a newly developed mineral polymer material and glass fibers. A pole Fire-Shield is simply a protective sleeve applied around a wood pole starting at ground level and extending up to about three times the height of the surrounding brush. These pole fire shields are of vital importance to California utilities because they effectively increase the survivability of transmission and distribution poles during raging brushfires. Electrical utility experience substantiates that fires consume unshielded poles in a few minutes. This creates an important energy delivery problem in the form of extended outages suffered by California consumers as the effort to replace poles typically takes one to several weeks to complete.

BlazeBarrier, Inc. will create a novel Fire-Shield based on its newly developed Inorganic Mineral Polymer (MIP) that is non alkaline. This Mineral Polymer is made at room temperature using a two-phase system that develops into a durable three-dimensional network structure. The fact that the material is made at room temperature contributes to its lower cost, energy efficiency, and environmental benefits.

The basic MIP material has the one disadvantage that cracks readily propagate because the material has no inherent crack arresting mechanism to stop a crack once it has started. BlazeBarrier's research proposes to solve this problem by creating a composite material that consists of glass fibers distributed throughout the MIP material. This custom tailored material will blend the excellent fire barrier properties of the Mineral Polymer with the toughness properties needed for it to function as a pole Fire-Shield.

Proposed Outcomes:
- Prototype test samples of new fire-shield material.
- A comprehensive mathematical model.
- Feasibility analysis based on the performance of the prototype material.

Anticipated Benefits:
- Potential low-cost alternative to the current expensive and less-effective pole shields that are being used in place of the asbestos shields that are being removed for environmental reasons.
- Potential to increase grid reliability by reducing outages caused by fires near transmission lines.

Project Status:
- 100% Complete.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report – Analysis in Progress.

Development of Low Cost High Efficiency Heterojunction Organic Solar Cell Using Inkjet and Screen Printing Techniques

EISG Grant Number: 03-04
PIER Area: Renewables
Principal Investigator: Ghassan Jabbour (520) 626-8324
Organization: University of Arizona
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of using the combination of inkjet and screen-printing technologies to fabricate low-cost organic solar cells.

Proposed Outcome:
- An all printed organic solar cell having efficiency greater than 4% will be fabricated and tested as part of the project.

Anticipated Benefits:
- Addresses the need for low-cost flexible thin-film solar cells with higher efficiency that would open up additional market applications for photovoltaic (PV) power generation.
- Potential to reduce the cost per kilowatt hour from organ solar cell systems by using low-cost fabrication technologies.

Project Status:
- Inkjet printing of the polymeric electrode into micro-lens array shape: Design electrode structure – 100%.
- Fabricate a prototype solar cell in which the polymeric electrode is inkjet printed onto a flexible plastic substrate, the organic active layer is screen-printed on the polymeric electrode and the metallic electrode is vacuum deposited on the organic active layer – 0%.
- Fabricate a prototype solar cell in which the polymeric electrode is inkjet printed onto a flexible plastic substrate, the organic active layer is screen-printed on the polymeric electrode and the metallic electrode is screen-printed on the organic active layer – 0%.

Development of Magnesium Diboride-Based Superconductor/Metal Matrix Composite Wire for use in Superconducting Transformers

EISG Grant Number: 03-03
PIER Area: Energy Systems Integration
Principal Investigator: Matthew Holcomb (310) 567-6397
Organization: Nove Technologies
Grant Amount: $72,060
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing a robust high-current magnesium diboride based superconductor/metal matrix composite wire and tape for use in superconducting transformers operating at temperatures in excess of 20K.

Proposed Outcome:
- Short and long (>10m) sections of wire will be developed and tested as part of the project.

Anticipated Benefits:
- Potential to reduce grid transformer losses by 40%.
- Potential to save 3,400GWh/year (valued at $27 million at 8 cents per kWh) by 2010 given a 10% market penetration.
- The proposed technology could reduce load loss by nearly a factor of two by the direct replacement of small to medium power-range (10-100 megavolt ampere (MVA)) conventional transformers with superconducting transformers operating at 25K.

Project Status:
- Synthesize high purity MgB2 powder with enhanced surface area – 80%.
- Incorporate MgB2 SMMC™ into in-house PIT fabrication process – 20%.
- Reconfigure in-house critical current measuring apparatus to accommodate 10cm length wire in an external magnetic field and 10m length wire in self-field – 80%.
- Reconfigure in-house critical current measuring apparatus with a rapid thermal cycling attachment – 0%.

Development of Single Fan Multi-Stack Exhaust Systems

EISG Grant Number: 01-27
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Mingsheng Liu (402) 554-2173
Organization: University of Nebraska
Grant Amount: $74,805
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of a single-fan multi-stack laboratory exhaust system that reduces annual fan energy use by 50%. California is the national and world leader for the development of high-level research technologies and consequently has large numbers of research and high-tech facilities in university campuses, government buildings, and industry plants. In these research facilities, exhaust fans run 24 hours-a-day 365 days-a-year to exhaust toxic air from the laboratories to the outside. The exhaust fans consume considerable electricity and contribute significantly to peak demand. This research will develop a single fan multi-stack system that will reduce exhaust fan annual energy consumption significantly.

Proposed Outcome:
- A prototype system will be fabricated and tested.

Anticipated Benefits:
- Potential to save on average 50% of the fan energy consumed by conventional laboratory exhaust systems.
- Retrofit payback period of only four years.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- EISG Program Administrator's Review of Final Report Draft in Process.

Development of Universal Software for Dissolved Oxygen Control in the Activated Sludge Process

EISG Grant Number: 02-22
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Alex Ekster (510) 657-7066
Organization: Ekster & Associates
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing control software capable of reliably regulating dissolved oxygen levels in the activated sludge process at wastewater treatment plants by quickly detecting hardware malfunctions that impact dissolved oxygen (DO) levels. Prototype DO control software will be tested at the 32 million gallon a day wastewater treatment plant located in Oxnard, California.

Proposed Outcome:
- Prototype control software will be developed and field-tested in a wastewater treatment plant.

Anticipated Benefits:
- Potential to reduce California energy consumption at wastewater treatment plants by 5-10%. If you assume only a 5% reduction in energy in 80 large treatment plants the energy savings would be approximately 49 GWh/year. There are about 800 treatment plants in California.
- Potential to reduce the number of accidental releases of improperly treated wastewater from treatment plants that seek to save energy by optimizing dissolved oxygen levels.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Report – Initiated.

Distributed Generation Drivetrain for Windpower Application

EISG Grant Number: 00-11
PIER Area: Renewables
Principal Investigator: Geoff Deane (805) 899-9199
Organization: Dehlsen Associates, LLC
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of an innovative drivetrain design for large-scale wind turbines. As wind turbines have grown, rates of revolution have decreased while power has increased thus increasing the torque seen on the turbines' gearboxes. Because of this detrimental scaling effect, as turbines have grown into the megawatt range, gearboxes now comprise increasing percentages of the total capital and lifetime costs, limiting the potential to reduce energy costs. Increasing failures of the larger gearboxes have resulted in the most substantial financial loss to the industry in recent years posing a serious concern for the industry as a whole. Dehlsen Associates has developed and engineered a new gearbox concept that addresses this high-torque low-rotational speed stumbling block.

This proposal outlines a project to demonstrate a 200 kilowatt prototype distributed generation drivetrain (DGD) and to develop the associated controller. The prototype is designed to eventually be installed on a wind turbine, but for the scope of this work will be tested on a dynamometer. Detailed real-time data will be acquired during the tests to quantify dynamic behavior, efficiency, load balance, and the success of the control strategy. Results of this study will lend insight into the development of a commercial-scale DGD system.

Proposed Outcomes:
- Prototype drivetrain for 200 kilowatt wind turbine.
- Prototype controller.
- Feasibility analysis based on performance of prototype controller and drivetrain.

Anticipated Benefits:
- Reduce the capital cost of installation of large wind turbines by 7%.
- Reduce lifecycle maintenance costs by 30%.
- Reduce the cost of power generation from 3.88 to 3.46 cents per kilowatt hour.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Draft Final Report Completed.
- Feasibility Analysis Draft Completed – Under Review.

Dry Steam Scrubbing for Impurity Removal from Geothermal Steam

EISG Grant Number: 02-13
PIER Area: Renewables
Principal Investigator: Paul Hirtz (707) 575-1310
Organization: Thermochem, Inc.
Grant Amount: $74,940
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a steam scrubbing technology that effectively removes and/or treats corrosive hydrogen chloride (HCl) in geothermal steam without superheat quenching or steam condensation so that the maximum amount of mass and energy can be retained for power generation. This pilot-plant study will test a hybrid calcite bed and amine treatment Dry Steam Scrubbing (DSS) process, and provide the information needed to determine if the process is technically and economically feasible for full-scale implementation.

Proposed Outcome:
- An existing pilot-plant facility for use in testing will be upgraded. This will involve design of bed configurations, a new containment vessel, water-wash regeneration system, corrosion monitoring system, plus fabrication and installation of new equipment. An optimized calcite bed configuration will be developed.

Anticipated Benefits:
- Potential to produce total heat savings of 40 British thermal units per pound (Btu/lb) steam, equal to 4.7 megawatts (MW) of gross heat energy or about 1.5 MW electrical power for a 20 MW plant.
- Potential to provide a 3% to 5% improvement in geothermal generation efficiency.

Project Status:
- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

Emission Monitoring of Nitric Oxide with a Mid-IR Solid State Laser

EISG Grant Number: 02-20
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Robert Cattolica (858) 534-2433
Organization: University of California, San Diego
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the detection limits for nitric oxide at combustion exhaust conditions using a mid-infrared solid-state laser. The ultimate goal of this research is to determine the feasibility of replacing traditional nitric oxide emission monitoring with a chemiluminescence analyzer (technology that is more than 40 years old) with new solid-state laser technology. This new laser technology, in addition to the potential for improved detection limits, can be multiplexed to provide measurements at multiple locations and by using other wavelengths access other species of interest: nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), Ammonia (NH_3), etc.

Proposed Outcome:
- An operational one-meter long combustion exhaust simulator will be constructed. A prototype mid-IR laser will be fabricated and tested in the combustion exhaust simulator.

Anticipated Benefits:
- In the near future, the mandated nitrogen oxides (NO_x) emission levels for gas turbines used for power generation will be so low that current NO_x measurement technologies will not be able to measure the emission levels accurately. This proposed technology has the potential to provide measurement accuracy sufficient to measure mandated levels well into the future.
- If successful, the proposed technology has the potential to accurately measure low levels of a wide variety of emission species further facilitating the setting and verification of various harmful emissions.

Project Status:
- Design of hardware and order material – 100%.
- Design and order gas control and temperature monitoring – 100%.
- Develop software to operate combustion simulator – 95%.
- Assemble and test combustion exhaust simulator – 95%.
- Model IR Absorption Spectra of Nitric Oxide – 50%.
- Design integration of exhaust simulator with PSI, Inc. – 100%.

End-Use Efficient, Environmentally Friendly Water Softening Device

EISG Grant Number: 03-05
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Nissen A. Jaffe (650) 961-1341
Organization: Material Methods, LLC
Grant Amount: $74,996
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of using an advanced Flow Through Capacitor in conjunction with new Ionic Charge Barriers to effectively soften tap water with low energy consumption.

Proposed Outcome:
- Flow Through Capacitor prototypes will be fabricated and tested as part of the project.

Anticipated Benefits:
- Potential to more effectively remove salts and other common contaminants, such as arsenic, perchlorate, permanganate, chromium, as well as other water-soluble heavy metal ions.
- Potential to reduce wastewater generation by 80% over reverse osmosis (RO) systems.
- Potential to reduce California energy consumption at wastewater treatment plants.
- Potential to operate at 60% of the energy usage compared to current state-of-the-art technology like RO.

Project Status:
- System design and fabrication – 100%.
- Evaluate rejection efficiency – 100%.
- Evaluate energy usage – 100%.
- Competitive comparison – 20%.

Energy Efficient Municipal and Industrial Odor-Control Equipment Study

EISG Grant Number: 01-09
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Bob Richardson (530) 474-4819
Organization: Pacific Rim Design & Development, Inc.
Grant Amount: $74,982
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a new energy efficient process for eliminating odors at wastewater treatment facilities. The proposed process reduces the amount of energy used by blowers and compressors. Consulting engineering firms across the country have been and are still specifying wet scrubbers and carbon absorbers more frequently than any other waste-water treatment and odor-control technology. Because this generation-old (30 years) technology employs large motors and is continuously operated in most facilities, it is a prime subject for energy-efficient design revision.

The older technology generally used larger amounts of electrical energy for two reasons. First because the motors used to drive blowers, pumps and other devices were less efficient than similarly sized motors built today. Second because the odor control equipment used oxidants that were less reactive than those used in this new technology. The oxidation of an odorous compound requires a specific amount of energy and the energy can be obtained from the chemical properties of the oxidant or from the mechanical environment in which the reaction occurs. In a reaction where the chemical oxidant itself is strong the reaction occurs readily with minimal "mechanical" assistance in the form of increased pressure, temperature, or other aids in the reaction environment.

In this pilot study we used hydroxyl radicals as oxidants which are significantly stronger than the hypochlorite ions used in conventional scrubbers, so we were able to oxidize the odorous compounds without the need for the additional electrical energy required to power larger pumps or compressors that were needed in the older odor control technology. The new odor control technology simply mixed the stronger oxidant into the foul air stream with low-pressure nozzles.

Proposed Outcomes:
- A pilot scale odor control plant will be installed at a Pacific Rim test site.
- Feasibility analysis based on the performance of the pilot plant.
- Procedures for safe operation of the new equipment in the wastewater treatment plant environment.

Anticipated Benefits:
- Reduce by 40% the amount of electrical energy used in odor control equipment.
- Improve odor removal efficiency over conventional equipment.
- Elimination of the large scrubber vessel saving the cost of the vessel, the cost of maintenance of the vessel and recovering the space that such large vessels occupy.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.

Energy Production from Bulk Wastewater

EISG Grant Number: 99-36
PIER Area: Renewables
Principal Investigator: Eric McFarland (805) 893-4343
Organization: University of California, Santa Barbara
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of producing wastewater microorganisms capable of efficient biosynthesis of hydrogen gas. The most promising microorganisms will be cultured and tested in a prototype sub-scale anaerobic digester. Anaerobic digesters have no free oxygen. Anaerobes get oxygen by the decomposition of compounds containing it. The technical objective of this project is to develop a means for the efficient, economic, biosynthesis of hydrogen gas (H_2) in wastewater anaerobic digesters for use as an environmentally clean fuel. Though scheduled first for automobile use, future electricity generation systems will increasingly use hydrogen if a cost-effective source of hydrogen gas becomes available. While hydrogen can be produced by reformation, decomposition, or electrolysis, these methods are relatively energy intensive or utilize non-renewable resources. An attractive alternative for H_2 production has been biosynthesis, however, to date the practical realization of bulk hydrogen synthesis from living organisms has not been achieved.

Proposed Outcomes:
- Combinatorial methodology for screening microorganisms capable of optimal H_2 production.
- Prototype bench top digester/bioreactor.
- Feasibility analysis based on performance testing of selected microorganisms in prototype bioreactor.

Anticipated Benefits:
- Demonstrate the effectiveness of combinatorial methodology in the screening of numerous genetically diverse mutant microorganisms for optimal H_2 production.
- Increase H_2 production from wastewater anaerobic digesters to a level that makes power generation commercially viable.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Fault Location Techniques for Distributing Feeders Containing Distributed Generation

EISG Grant Number: 02-04
PIER Area: Energy Systems Integration
Principal Investigator: Adly Girgis (864) 656-5936
Organization: Clemson University
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of a computational strategy for determining the fault location in a transmission network containing distributed generation resources. The proposed strategy will be based on an analysis of the voltage and current waveforms on the three phase lines at various points in the distribution network.

Introducing distributed generation changes the power flow in distribution systems from a traditionally unidirectional to multi-directional power flow. Thus, there is a need to develop a new method for fault location. Locating faults in a distribution feeder is essential to speed the restoration of service and minimize the outage time of the distribution feeder. The proposed method considers the following factors:

1) The distribution feeder may contain single-phase loads, two-phase loads and three-phase loads so system unbalance should be considered.
2) The feeder may include any number of distributed generators of different types along the feeder.
3) Data at the distributed generators may or may not be communicated to the substation computer.

The new fault location method to be developed will be based on the three-phase components of the transmission line. The method can be used for balanced or unbalanced systems and will be based on the phasor quantities of the voltage and current waveforms at the substation.

Proposed Outcome:

- Two algorithms will be developed and utilized. First, an algorithm for calculating the voltage and current phasor quantities needed for the fault location algorithm using three-phase fault analysis will be developed. Second, a signal-processing algorithm, such as DFT and Kalman filtering, will be developed in order to obtain the phasor quantities when the voltage and current waveforms are obtained from EMTDC software simulations.

Anticipated Benefit:

- Potential to provide California utilities with the ability to incorporate Distributed Generation (DG) into their distribution systems while maintaining the current level of system reliability.

Project Status:

- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft Completed – under Review.
- Feasibility Analysis Report – Initiated.

Feasibility of a Hydrogen Blower Design for Fuel Cell Recirculation Applications

EISG Grant Number: 02-19
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: J. Patrick Sterchi (760) 788-7699
Organization: H2Systems, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of using a unique blower design for recirculation of anode tail-gas in a hydrogen-fueled fuel cell system application. The net result of effective recirculation in a hydrogen fuel cell is a reduction in the amount of platinum catalyst that must be used in production. Significant savings in the cost of each fuel cell unit is the result since platinum is very expensive. A fuel cell with proper recirculation could cut material costs by as much as 30%. This would result in an estimated savings of $0.003/kWh over the life of the power plant.

Proposed Outcome:
- A 7cm blower prototype will be constructed. Experimental data will be used to produce a blower performance curve based showing flow rate, pressure rise and power consumption for several operating points.

Anticipated Benefits:
- Potential to produce a system with a low-volume production cost of $250 to $300 per unit.
- Potential to produce a hydrogen blower design that will meet the recirculation needs of a 1-10kW fuel cell power plant.
- Potential to provide a 25-30% direct savings on the fuel cell material platinum catalyst that must be used in production. This may result in significant savings in the production of fuel cell units since platinum is very expensive.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Field Feasibility Determination of a Novel Energy-Saving Refrigeration Controller

EISG Grant Number: 01-12
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Patrick D. French (303) 792-5615
Organization: ADA Technologies, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a frost sensor microcontroller and special algorithm to fine-tune the defrost cycle for industrial/commercial refrigerators by activating and terminating defrost cycles only when frost appears on the evaporation coil. ADA Technologies, Inc. will perform a field evaluation of this novel device and determine the actual energy savings under real-world conditions. For this project, the prototype controllers will be installed in operating commercial refrigeration systems in California to quantify and document the actual energy savings and the associated improvement in temperature regulation. The stage will be set for cost/benefit calculations by determining the actual energy savings of demand defrost under real-world conditions.

Proposed Outcomes:
- Prototype frost sensor microcontrollers for use in field tests.
- A model to predict energy savings.
- Modified firmware that includes additional alarm conditions.
- Feasibility analysis based on the performance of the prototype system.

Anticipated Benefits:
- The proposed demand defrost system has the potential to reduce refrigerator energy consumption from 6-15% by reducing the number and length of defrost cycles.
- This has the potential to save .034 quads of electrical energy from commercial refrigeration in the U.S. based on the following assumptions (.6304 quads consumed in this category, 11% improved efficiency, and 50% market penetration).

Project Status:
- Prepare Equipment for Field Testing – 100%.
- Prepare for Field Test – 100%.
- Collect, Process and Analyze Data – 75%.
- Develop Energy Savings Calculator – 0%.

Field Validation of a Model of Generation and Migration of Methane and Other Gases in Landfills

EISG Grant Number: 00-26
PIER Area: Renewables
Principal Investigator: Richard Prosser (714) 632-9969
Organization: GC Environmental, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of field testing a simulator that will allow the user to predict and monitor the behavior of landfills. The municipal solid waste (MSW) that is deposited in landfills undergoes anaerobic decomposition and produces a gaseous mixture called landfill gas (LFG), which consists mostly of methane and carbon dioxide (and some smaller amounts of oxygen and nitrogen) together with trace amounts of a number of volatile compounds (VOC). A typical landfill produces about 4-5 million standard cubic feet per day of LFG with larger landfills producing upwards of 50 million SCFD. Understanding how landfill gas is generated and migrates within landfills is of paramount importance to improve the collection efficiency of LFG without poisoning LFG generation by pulling air into the waste.

The use of LFG for generating electricity is a promising approach both in terms of conserving energy and also for reducing air pollution while producing electricity since the VOC in LFG are burned in the combustion chamber. LFG has the potential of becoming an abundant and stable renewable source of energy for California and the nation. The challenge that exists is to collect all the gas that is produced in the landfills, and not allow it to be inadvertently lost to the atmosphere as fugitive emissions. This project will help optimize landfill gas collection and utilization systems for energy production.

Proposed Outcomes:
- Develop a validated simulator that can predict the rate of gas generation and migration, flow of the leachates, pressure build-up in the landfill and the composition of the gas and air on top surface of the landfill and in the surrounding soil.
- Help increase the understanding of dynamic subsurface behavior in relation to environmental and physical process changes.

Anticipated Benefits:
- Reduce landfill gas emissions, which will decrease air pollution and increase LFG power plant generating potential.
- Increase the captured amount of useful landfill gas for power generation.
- Reduce landfill gas power plant costs by increasing efficiency.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Flexible Low Emissions Combustor for Renewable Fuels

EISG Grant Number: 01-16
PIER Area: Renewables
Principal Investigator: John T. Kelly (408) 982-2302
Organization: Altex Technologies Corporation
Grant Amount: $74,959
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a flexible low-emissions combustor (FLEC) for renewable fuels that are poorly formed, inconsistently sized and contain high moisture. FLEC uses special features to handle inconsistently sized and high moisture wastes. In addition, an aggressive ash handling method is utilized to avoid deposition on heat transfer surfaces and passages, and positively remove ash from the system. With FLEC, nearly all plant wastes can be converted into energy at a cost that will be close to that of converting fossil fuels and will further the use of plant wastes for power generation, while helping reduce the air pollution associated with electricity generated using fossil fuels.

Proposed Outcomes:
- A prototype test FLEC.
- Feasibility analysis based on performance and economic evaluation of prototype.

Anticipated Benefits:
- Provide a cost effective and environmentally clean solution to converting low-value biomass materials to useful electrical energy.
- Reduce the cost of biomass combustion by 30% relative to grate based and fluidized bed systems.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Draft Completed – Under Review.

Flywheel Energy Storage Units in Power Distribution Networks

EISG Grant Number: 01-02
PIER Area: Energy Systems Integration
Principal Investigator: John Balachandra (916) 278-7347
Organization: ELCOM
Grant Amount: $74,888
Status: Active

Project Description:
The purpose of this project is to research the feasibility of incorporating flywheel energy storage units into power distribution systems to maintain power quality and voltage stabilization. A 2 kW Dynamic Rotary Uninterruptible Power Supply (DRUPS) flywheel system will be incorporated into a micro-power distribution system with a variety of loads attached to different buses. Power quality anomalies will be introduced into the system to determine the ability of the DRUPS to maintain system integrity, reliability, efficiency, voltage stability and power quality.

The actual testing of the system would be preceded by computer simulations of the DRUPS and the dynamics compared with the actual test results.

Proposed Outcomes:
- Assemble a micro power distribution system with a 2 kW Flywheel Energy Storage Unit integrated into the system.
- Determine the ability of the Energy Storage unit to maintain power quality within a micro power distribution system.

Anticipated Benefits:
- A capability to respond to and mitigate power distribution system voltage variations of greater than 15% plus or minus within 150 milliseconds.
- A capability to respond to voltage perturbations on the supply side by carrying the load for a period greater than 15 seconds.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Flywheel System for Bulk Energy Storage

EISG Grant Number: 03-02
PIER Area: Energy Systems Integration
Principal Investigator: Christopher Gabrys (775) 853-4651
Organization: Cobalt Energy
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a new-technology flywheel system concept for providing low-cost bulk energy storage that can improve the reliability and dispatchability of renewable electricity generation.

Proposed Outcome:
- A subscale flywheel system will be fabricated and tested as part of the project.

Anticipated Benefits:
- Potential to provide energy storage at a cost of $2/Wh capacity by increasing cycle life to 100,000 and achieving 95% efficiency.
- Potential to reduce the cost of energy storage by 80% over storage batteries.

Project Status:
- Send out drawings for part fabrication – 100%.
- Assemble flywheel system – 100%.
- Test flywheel system – 20%.
- Perform an economic analysis – 0%.

Geothermal Reclaimed Water Turbine

EISG Grant Number: 02-15
PIER Area: Renewables
Principal Investigator: Doug Jung (707) 523-4585
Organization: Two-Phase Engineering and Research
Grant Amount: $75,000
Status: Pending

Project Description:
The purpose of this project is to research the feasibility of installing down-hole turbines into geothermal injection wells at geysers.

Proposed Outcome:
- A prototype down-hole turbine will be installed and tested.

Anticipated Benefits:
- Potential to capture at least 25 MWe of electrical power generation currently available as a byproduct of environmental wastewater disposal.
- Potential to provide a system to acquire this energy that could be paid off in 2 to 3 years at $20 per megawatt hour.

Project Status:
- Agreement in Progress
- Start date to be determined.

Gyroton Rotary Engine Project: A Controllably Variable Compression and Displacement Rotary Engine

EISG Grant Number: 01-05
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Geoff Deane (805) 899-9199
Organization: Dehlsen Associates, LLC
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of constructing a rotary engine based on geometries that produce and follow an idealized asymmetric complete-expansion cycle. The proposed engine design provides a high power to weight ratio and high thermodynamic and mechanical efficiencies. Because it asymmetrically expands its working gases, the exhaust temperature and pressure are significantly lower than conventional designs, making it less acoustically and thermally obtrusive. The geometry allows dynamic control of both the engine's compression ratio and the engine's total displacement allowing significant improvements to efficiency in various operating conditions, such as using varied fuels and operating under low engine load requirements.

Proposed Outcomes:
- A 10 HP prototype engine will be constructed.
- Feasibility analysis based on the performance of the prototype engine.

Anticipated Benefits:
- Increase the fuel efficiency of internal combustion (IC) engines by improving the thermodynamic and mechanical efficiencies of the engine, which are needed to make IC engines competitive in the distributed generation market.
- Make available a more efficient IC engine with a capital cost around $400/kW.

Project Status:
- Design – 90%.
- Fabrication and Assembly – 90%.
- Testing – 35%.

High Efficiency Organic Thin Film Solar Cell

EISG Grant Number: 02-06
PIER Area: Renewables
Principal Investigator: Shalini Menezes (805) 497-2677
Organization: InterPhases Research
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of a low-cost organic thin-film solar cell device that can be fabricated using a simple robust process for organic/polymeric materials. Barriers to the widespread use of solar cells (photovoltaics) are mainly cost related. Organic solar cells have many practical advantages ensuring their low-cost production and product competitiveness. They include:

- Simple, non-toxic and inexpensive materials.
- Lightweight and flexible plastic substrate.
- Amenability to state-of-the-art robust processing technologies such as coating and continuous roll-to-roll production.
- Large-area and high-volume production.

Lightweight flexible organic solar cells will find applications in portable electronic devices, portable electricity systems, electric vehicles, space systems and building integrated PV among others. Organic solar cells can also be transparent or mono-colored and thus can be used in see-through applications such as windows and sunroofs.

Proposed Outcome:

- A solar cell will be constructed based on the proposed concept.

Anticipated Benefits:

- Proposed technology has the potential to increase the conversion efficiency of organic thin-film solar cells to at least 5% while keeping costs low.
- Proposed technology has the potential to provide low-cost high-volume production of flexible thin-film solar cells from inexpensive easily-processed organic and polymeric materials.

Project Status:

- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

High Speed Light Activated On/Off Thyristor

EISG Grant Number: 99-17
PIER Area: Energy Systems Integration
Principal Investigator: David Giorgi (858) 452-8787
Organization: OptiSwitch Technology, Inc.
Grant Amount: $74,900
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing an all-light controlled on/off thyristor power switch. A thyristor is an electronic device that conducts electricity in one direction only. This effort leverages prior development of a light activated switch capable only of turn-on that was developed for surge protection applications. This effort will add turn-off capability to the light activated switch thereby extending its potential use into a wide range of electrical devices such as inverters, filters, pulse-width modulators, etc. These devices can benefit from smaller, lighter and more efficient high-speed power switches. Preliminary physical tests will be performed to demonstrate feasibility.

Proposed Outcomes:
- Using 2D-simulation code, a mathematical model will be developed of the light controlled thyristor.
- Specifications for required laser light source.
- Process steps for device fabrication.

Anticipated Benefits:
- Increase turn-off current density capability over existing thyristor switches by a factor of four to 100 A/cm2 (amps per square centimeter) while maintaining a 1µs (micro-second) turn-on time.
- This technology will enable power switches to be made smaller and lighter than existing switches, which should reduce manufacturing costs.
- Light activated switches are more reliable because they are not susceptible to faulty triggering from electrical noise.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report Drafted – Analysis in Progress.

Highly Conductive, Water Insoluble & Thermally Stable PEM from Functionalized POMs

EISG Grant Number: 00-15
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Yuhong Huang (818) 727-9786
Organization: Chemat Technology, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a polymer membrane for a proton exchange membrane (PEM) fuel cell that is highly proton conductive, water insoluble and stable across a wide temperature range. The proposed research is to develop highly proton conductive and thermally stable inorganic electrolytes for a proton exchange membrane fuel cell based on functionalized polyoxometalates (POM) membrane. Polyoxometalate has been proven to have high temperature proton conductivity (0.17 S/cm) and much lower cost than Nafion.

Operation at low and high temperatures is desirable because it allows a variety of operating conditions to be used. Low temperature electrolytes, such as 25 to 60°C, are suitable for portable fuel cells. High temperature electrolytes, 120 to 140°C, are desirable for high power larger fuel cells. High temperature fuel cells reduce the impact of carbon monoxide poisoning in reformate air fuel cells and allows attainment of high power density.

Success in developing alternative, thermally-stable conducting materials could have a tremendous impact on fuel cell technology. By eliminating the hydrous component, it is anticipated that water re-circulation hardware will not be necessary and thermal management issues will be relieved, thus greatly simplifying the overall fuel cell system.

Proposed Outcomes:
- Methodology for producing polymer membranes with the specified characteristics.
- Feasibility analysis based on single cell performance testing of the most promising prototype membrane. Fuel Cell Energy will conduct cell testing. Samples will be sent to JPL NASA for evaluation.

Anticipated Benefits:
- Increase PEM fuel cell reliability and lifespan.
- Reduce PEM fuel cell manufacturing costs by reducing the cost of the membrane from $500-$1000/m2 for Nafion to $2/m2 for the proposed membrane.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

High-Volume Manufacturing for Low-cost, Flexible Solar Cells

EISG Grant Number: 01-18
PIER Area: Renewables
Principal Investigator: Shalini Menezes (805) 497-2677
Organization: InterPhases Research
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a new flexible thin-film solar cell based on negatively doped (n) copper indium diselenide (CIS) with fewer cell components relative to the state of the art, positively-doped (p)-CIS cell. The CIS PV cells are more efficient and reliable than other thin-film technologies. The state-of the-art technology is based on positively doped (p)-CIS rigid glass panels, fabricated with expensive, hazardous methods that are difficult to scale up for mass production. The proposed n-CIS cell will circumvent these issues. It will use fewer cell components and a simpler, cheaper manufacturing approach. The flexible n-CIS cell will be produced via electrodeposition on a metal tape for large volume manufacture. Low cost electrodeposition incorporates environmental benefits, low temperature growth, efficient material utilization and practical deposition rates. The same laboratory-scale equipment can be used for a MW-scale plant production.

Proposed Outcomes:
- Manufacturing methodology for deposition of n-CIS film.
- Prototype n-CIS PV cell.
- Photoelectrochemical and composition analysis.
- Efficiency and stability analysis.
- Feasibility analysis based on performance of prototype cell.

Anticipated Benefits:
- Reduce thin film production cost from $26/m2 to about $2/m2 resulting in a 75% reduction in PV module cost.
- Eliminate the need for cadmium in the PV modules which reduces the potential for environmental damage.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Hydrogen-Methane Waste Fermentations for Clean Electricity Generation

EISG Grant Number: 02-09
PIER Area: Renewables
Principal Investigator: John Benemann (925) 939-5864
Organization: Benemann Associates
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate a two-stage process for the anaerobic digestion (bacterial fermentation) of wastes to produce a mixed hydrogen methane fuel known to result in clean electricity generation particular low in nitrogen oxides (NO_x) emissions. The hydrogen fuel will be produced in the first stage and methane in the second, with the process yielding a desirable ratio of hydrogen gas (H_2) to methane (CH_4) ranging from about 0.3:1 to 1:1 H_2:CH_4 on a volume basis. Practical applications of this process will expand the potential applications of anaerobic digestion (AD) of wastes at a minimal incremental cost over conventional processes. The effect will be to reduce air pollution and allow additional electricity production in California non-attainment areas.

Proposed Outcome:
- Bench-scale bioreactors using simulated and actual food and food-processing wastes will be utilized. A technical and economic feasibility analysis will be carried out based on the experimental results.

Anticipated Benefits:
- Potential to capture at least 25 MWe of electrical power generation currently available as a byproduct of environmental-wastewater disposal.
- Potential to provide a system to acquire this energy that could be paid off in 2 to 3 years at $20 per megawatt hour.

Project Status:
- Project Start-up – 100%.
- Initial Experimental Work, System Testing – 100%.
- Mesophilic Operations with Simulated Food Wastes – 50%.
- Thermophilic Operations with Simulated Food Wastes – 0%.
- Operations with Simulated Food Processing Wastes – 0%.

IEM's Low Cost Building Performance Infrared Camera

EISG Grant Number: 01-19
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Zack Mian (518) 449-5504
Organization: International Electronic Machines Corporation
Grant Amount: $74,946
Status: Active

Project Description:
The purpose of this project is to research the feasibility of incorporating cost-cutting innovations in the design of an infrared camera that will reduce the retail cost from $12,000 to less than $2,500, thereby expanding their use in energy audits of commercial and residential structures.

Performance monitoring projects across the U.S. have documented the potential to conserve 15% to 30% of energy used through improved operation and maintenance practices. An important step towards performance monitoring is to establish the energy efficiency of the building. Energy losses can come from a number of areas: direct loss from windows/doors, inadequate caulking/weather stripping, lack of duct and/or piping insulation and missing insulation in ceilings, walls and/or floors.

During an energy audit, an expert performs heat loss measurements on the property. Thermal infrared imaging cameras have become an invaluable tool in performing energy audits in commercial as well as residential applications. The infrared camera has the ability to display the energy loss as an at-the-source image. This image provides an easy to use picture to assist the energy auditor. The high investment cost of an infrared camera is prohibitive to many energy contractors, and a less-costly energy-loss tool with the same high-quality image properties will greatly increase their availability and use in the industry.

Proposed Outcomes:
- A prototype infrared camera unit.
- Field study by energy performance contractors.
- Feasibility analysis based on performance of prototype system.

Anticipated Benefits:
- Potential to improve energy audits performed by energy auditors/consultants, building contractors, electrical inspectors and utility companies.
- Improved operating and maintenance practices have the potential to reduce building energy consumption by 15-30%.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.

Improved Insulation for Buildings and Refrigeration

EISG Grant Number: 00-33
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Jeffrey Zuker (760) 325-4003
Organization: Jeffrey Zuker
Grant Amount: $74,525
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a low-cost perlite-based ceramic insulator material to develop a thermal insulating material with high R-value for buildings and refrigeration. In the construction and refrigeration industries insulation values are currently limited to a maximum of R-10 per inch. The most common materials have R-factors of from 2.5 to 8. Therefore a structure must have relatively thick and expensive walls to have a high thermal insulation value.

The proposed improvement to building and refrigeration insulation is a lightweight ceramic insulation made of low-cost readily-available materials. Research shows that a ceramic insulation made with perlite and other materials can produce an insulating material with an R factor of up to 40. Perlite based ceramic insulators have unique properties that make them suitable for building and refrigeration applications. To make the product applicable for most insulating situations, the product should be hydrophobic, easy to manufacture, and have certain mechanical properties to make it marketable.

Proposed Outcomes:
- Produce a high-efficiency ceramic thermal insulating material made from low cost materials.
- Produce a product that can be cast or molded into sheets or other desirable shapes.

Anticipated Benefits:
- Insulation material with an R value of up to 40.
- Ceramic insulation having sufficient mechanical strength to be self-supporting and easy to handle.
- Provide leads to improving energy efficiency in buildings and refrigeration systems.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.

Improved Performance of Energy Recovery Ventilators Using Advanced Porous Heat Transfer Media

EISG Grant Number: 00-07
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Mark Tillack (858) 534-7897
Organization: University of California, San Diego
Grant Amount: $74,762
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using advanced porous media to increase the heat transfer efficiency of heat recovery ventilators to 90% (current technology is 50-80% efficient). The current trend toward sealing houses to reduce air and moisture infiltration makes them more energy efficient and reduces home energy costs. Depending on the local climate, appliance use and sealing method tighter houses can be 15% to 30% more energy efficient. However, as homes and commercial buildings become more leak tight, adequate ventilation becomes increasingly important in order to avoid air quality problems.

If a house is constructed tighter than 0.35 air changes per hour, any pollutants generated in the home can accumulate and reduce the indoor air quality to unhealthy levels. If fresh outside air is brought in through an open window to alleviate this problem, this air may be excessively hot, cold or humidity-laden and require conditioning at added expense. Energy recovery ventilators (ERVs) use air-to-air heat exchangers to minimize the additional energy needed to condition this fresh air. The heart of the system is the heat exchanger, which in some cases is also used to aid in filtration and/or humidity control. Substantial improvements in heat transfer efficiency are possible using modern low-cost gas-phase heat exchanger technology. Increasing the heat transfer effectiveness to 90% would provide a factor of 2-5 decrease in energy loss.

Proposed Outcomes:
- Fabrication of porous medium samples.
- Optimized heat recovery ventilator design.
- Feasibility analysis based on performance of test samples.

Anticipated Benefits:
- Provide a cost effective and energy efficient means of maintaining indoor air quality in structures that are built airtight.
- Encourage the construction of airtight houses that are 15%-30% more energy efficient.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Industrial Energy Recycling Process and Products

EISG Grant Number: 03-09
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Rick West (805) 543-4520
Organization: Distributed Power Technologies, LLC
Grant Amount: $74,970
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing an inverter with a user-friendly interface that can be used by power supply manufacturers to recycle the electrical energy used to test new power supplies as part of the manufacturing process.

Proposed Outcome:
- Two 48 volt direct current (Vdc), 15 kilowatt (kW), 3-phase prototype power recycling units will be fabricated and tested as part of the project.

Anticipated Benefits:
- Potential to reduce the power consumption used for power supply burn by a minimum of 91%.
- Potential to provide an 86% reduction in heat generation over conventional burn.

Project Status:
- Finalize design of prototype system – 100%.
- Fabricate two 48Vdc, 15kW, 3-phase prototype power recycling units – 40%.
- Finalize test plan – 100%.
- Conduct laboratory testing of prototype units – 20%.
- Conduct field-testing of prototype unit at a power supply manufacturing facility – 0%.
- Conduct a manufacturing cost analysis of the proposed device – 0%.

Instant Snap-in Load Shed Device for Incandescent Lighting

EISG Grant Number: 02-10
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Andrew Bierman (518) 687-7100
Organization: Rensselaer Polytechnic Institute
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to develop and test the electronic components necessary to receive the load-shed signal and dim an incandescent lamp accordingly. Once these components are developed, they will be tested under electrical and thermal conditions typically found in an incandescent lamp socket. A laboratory prototype of the snap-in incandescent load-shed device will be developed and tested under a variety of load-shed conditions.

Proposed Outcome:
- A laboratory prototype of the snap-in socket adaptor device will be fabricated. An electrical and control component necessary to receive a power-line signal and dim incandescent lamps to a preset level on demand will be developed.

Anticipated Benefit:
- Potential to provide a device that would allow building owners or utilities to reduce lighting load demand by between 30% and 50% instantly without adversely affecting the operation of electrical equipment or the ability of people to work with adequate lighting.

Project Status:
- Identify necessary electrical components and circuitry to allow for the device to receive a power line signal and dim an incandescent lamp – 100%.
- Obtain commercially available components and build initial prototype device – 100%.
- Conduct testing to determine the electrical and thermal operating parameters of a typical incandescent lamp socket and fixture – 100%.
- Develop an apparatus to simulate these conditions in a laboratory setting – 0%.
- Test the components developed in task 1 under these conditions to ensure that the prototype device will be able to operate successfully over prolonged exposure to these conditions – 100%.
- Develop a prototype-miniaturized version of the snap-in, incandescent load-shed device – 50%.
- Conduct bench-top, laboratory testing of the final prototype device to demonstrate its ability to provide the load-shedding capacity necessary on-demand in response to a power line signal, under a variety of conditions and load-shed scenarios – 0%.

Integrating Evaporative Cooling with Dynamic Insulation for Occupant Thermal Comfort

EISG Grant Number: 02-12
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Diane Griffiths (203) 857-0200
Organization: Steven Winter Associates, Inc.
Grant Amount: $74,913
Status: Active

Project Description:
The purpose of this project is to research the feasibility of reducing peak cooling loads and increasing design day comfort in evaporatively cooled residences though the construction of a dynamic building envelope that uses exfiltrating air to reduce exterior wall and ceiling conduction loads and lower interior surface temperatures. The primary tasks proposed for this project include the construction and bench testing of dynamic ceiling and wall systems in order to determine the airflow that must be directed through these assemblies in order to completely offset energy gains. In addition to thermal performance, other issues to be examined will include ease of construction, building code compliance, first cost and aesthetics. Energy modeling using DOE-2 software will also be conducted in order to assess the thermal comfort on design days that would result from integrating an evaporative cooling system with dynamic insulation.

Proposed Outcome:
- A testing apparatus capable of simulating the performance of the proposed dynamic ceiling and wall designs will be fabricated (dynamic ceiling and wall test panels). A DOE-2 analysis will be conducted.

Anticipated Benefits:
- Potential to reduce peak cooling loads by up to12%.
- Potential to provide a one degree Fahrenheit design day reduction in ceiling and exterior wall surface temperature, therefore improving occupant thermal comfort.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed behind Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Report – Analysis in Progress.

LEAMS (Low Emissions Atmospheric Metering Separator)

EISG Grant Number: 01-07
PIER Area: Environmental Area
Principal Investigator: Doug Jung (707) 523-4585
Organization: Two-Phase Engineering and Research
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a design change to reduce the noise level of the prototype LEAMS by 10 to 20 dB, thus resolving the main technical obstacle to commercialization. Additional design changes will be tested that will improve system performance and capacity. The separator is used for geothermal drilling, well-testing, power plant start-up and emergency venting use. The LEAMS is designed to be environmentally friendly, intrinsically safe and have multi-purpose use in the geothermal industry.

Proposed Outcomes:
- Modifications to the prototype will be fabricated and installed.
- Feasibility analysis based on performance testing of modified prototype.

Anticipated Benefits:
- LEAMS system has significant environmental advantages over the Blooie Muffler, which is currently used to control the emissions from geothermal well drilling.
- The Glass Mountain Geothermal Area in northern California may contain up to 500 Mw of geothermal power that cannot be recovered with existing technology due to regulatory requirements. It is anticipated that LEAMS will satisfy these regulatory requirements, making this valuable resource available to benefit California ratepayers.
- Reduces drilling and well-testing costs.
- Increases physical safety around the geothermal drill rig.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Low Cost Hybrid Inverters Utilizing IGBTs and SCRs

EISG Grant Number: 00-30
PIER Area: Environmental Area
Principal Investigator: Giri Venkataramanan (608) 262-4479
Organization: University of Wisconsin, Madison
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a low-cost hybrid inverter/converter utilizing SCRs and IGBTs that could be used in variable speed drives and distributed generation systems such as photovoltaics (PV) and wind turbines. The project is aimed at reducing the cost and improving the reliability of inverters used in high-power adjustable speed drives and distributed power generation systems.

Power inverters, used to convert electricity from dc to ac, constitute an enabling technology in a wide range of advanced electrical energy applications. Their application in adjustable speed motor drives continues to transform several industrial processes resulting in dramatic performance and efficiency improvements. Any reduction in inverter cost will result in broadening their application and lead to further improvements in energy efficiency. Inverters also form an integral part of modern distributed utility-grade power generation systems such as photovoltaic systems, wind energy systems, fuel cells and micro-turbine systems. These applications also stand to gain from the reduced costs of inverters. The proposed inverters will realize higher reliability, lower cost and higher performance when compared to conventional pulse width modulated inverters using IGBTs or line-commutated inverters using SCRs respectively.

Proposed Outcomes:
- Develop computer simulation based on existing models.
- Design and build circuit.
- Quantification of performance based on working design.

Anticipated Benefits:
- May reduce converter/inverter costs by up to 75%.
- Increased reliability.
- Potential increase in performance output.
- May eliminate poor input power quality.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Low Cost Microchannel Reformer for Hydro Production from Natural Gas

EISG Grant Number: 99-14
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Darby Makel (530) 895-2771
Organization: Makel Engineering Inc./Darby B. Makel
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of fabricating prototype microchannel reformers for converting natural gas to hydrogen for use in fuel cells. Innovative fabrication strategies will be investigated and tested.

Proposed Outcomes:
- Two prototype reformers that employ different fabrication strategies.
- Performance results from prototype tests.
- Methodology for fabricating small low-cost scaleable natural gas reformers.

Anticipated Benefits:
- Enable the mass production of low-cost natural gas reformers, thus significantly reducing the manufacturing cost of integrated fuel cells.
- Enabling technology that would allow small residential and commercial fuel cells to operate from the abundant and inexpensive natural gas supplies in California.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Low Cost, Energy Saving Motor Controller for Residential and Industrial Buildings

EISG Grant Number: 02-02
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Patrick Chapman (217) 333-4694
Organization: University of Illinois, Urbana
Grant Amount: $69,482
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of integrating a unique controller and a specially designed three-phase motor. The controller allows the motor to be driven with single-phase power and varies the speed of the motor to follow the load. By matching the speed to the load, the motor can be made to operate at its maximum efficiency operating point.

Small single-phase electric motors do not match speed to load and so collectively waste an enormous amount of energy on a worldwide scale. These small motors are used because of the wide-spread availability of single-phase power for appliances and heating and air conditioning systems. There is a potential to save California homeowners up to 25% on their alternating current (AC) consumption (AC power is single-phase power) by making the more efficient three-phase motor available for small appliances operating on single-phase power.

Proposed Outcome:
- A 500 W prototype will be fabricated and tested.

Anticipated Benefits:
- Potential to demonstrate greater than 70% motor efficiency over a 10:1 speed range.
- Potential to achieve a unit cost of less than $40.
- Potential to save California homeowners up to 25% on their AC energy consumption.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Low-Cost, High Efficiency Solar Cell Fabrication Using Inkjet Printing

EISG Grant Number: 01-26
PIER Area: Renewables
Principal Investigator: Neil Kaminar (408) 524-9739
Organization: SunPower Corporation
Grant Amount: $74,948
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of using low-cost high-resolution inkjet printing technology to fabricate high-efficiency solar cells. The process SunPower uses to fabricate its solar cells is unique in the solar industry. SunPower's manufacturing is more similar to processes and equipment used by the integrated circuit industry than to other solar cell companies. Achieving high cell efficiency requires patterning very fine device features, about 0.004 of an inch (100 µm) in size. Presently, SunPower uses photolithographic processing to define the very fine patterns needed, but this is very costly. To make lower cost cells, lower cost equipment and processes must be found while not sacrificing the resolution required for high efficiency.

Inkjet printing offers a possible solution. Resolution of common desktop inkjet printers, selling under $200, are typically 720 DPI (dots per inch), equating to 35 µm dot spacing. They are also easy to use – just load up the desired pattern and press print. Finally, they are "off contact" meaning that only the ink touches the substrate, unlike other printing techniques.

Proposed Outcome:
- The project will modify a commercial inkjet printer and formulate special inks, which will be used to physically test the concept.

Anticipated Benefits:
- Potential to achieve cell efficiencies of 21% without an increase in manufacturing cost.
- Potential to reduce PV module cost to $1.92 dollars per watt by 2005.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Materials for Fast-Response Solid Oxide Fuel Cells (SOFCs)

EISG Grant Number: 01-04
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Lutgard De Jonghe (510) 486-6138
Organization: University of California, Berkeley
Grant Amount: $74,997
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a specially formulated composite anode layer on the thin ceramic electrolyte film in a Solid Oxide Fuel Cell (SOFC). The anode layer will be low cost and tuned to the thermal expansion coefficient of the ceramic electrolyte film to permit rapid thermal cycling. Within the context of intermittently operating systems is the capability of the fuel cells to withstand not only repeated thermal cycling but also rapid heating as well. To date there is no satisfactory answer to reliability questions for SOFCs in intermittent distributed power scenarios. The basic problem is one of materials compatibility. The present work intends to remedy this problem by identifying and evaluating electrode materials that can support the thin film solid oxide electrolyte in the SOFC through conditions of rapid thermal cycling.

Proposed Outcomes:
- Prototype laboratory scale SOFC membranes constructed with composite anode layer.
- Feasibility analysis based on characterization and performance of prototype membranes to withstand rapid thermal cycling while maintaining a high power density (300 mW/cm2).

Anticipated Benefits:
- Increase the reliability of SOFCs used in distributed generation applications by making them capable of rapidly cycling from room temperature to an operating temperature of 850°C.
- Reduce membrane cost to less than $65/ft^2.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Methane Sensor for Control and Automation

EISG Grant Number: 02-08
PIER Area: Energy Systems Integration
Principal Investigator: Mourad Baraket (212) 217-2222
Organization: Carthago International Solutions, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to introduce a new infrared sensor technology for the detection and measurement of methane (CH_4) to control and automate the collection of biogas and the operation of distributed power generators (e.g. microturbines and fuel cells). The implementation of this technology in landfills will improve landfill-gas-to-electricity (LFGTE) conversion efficiency, enhance system reliability and lower operation and maintenance costs, thereby increasing the value, cost competitiveness of LFGTE systems.

Proposed Outcomes:
- Fabricate a bench-scale sensor prototype for extensive tests to determine the sensor performance.
- Demonstrate the following operating parameters:
  a) The CH_4 concentration range of 10-80% by volume will be determined.
  b) Lowest detection: 5% by volume of CH_4 in air.
  c) Measurement accuracy: 2% full scale.

Anticipated Benefits:
- Potential to increase the conversion efficiency of power generators at an estimated rate of 10 to 15%.
- Potential to provide a safe and reliable way of collecting biogas for green power generation.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Microturbine Based Building Energy System

EISG Grant Number: 01-14
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Nissen A. Jaffe (650) 961-1341
Organization: Nissen A. Jaffe
Grant Amount: $68,058
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a variable partial-recuperator exhaust by-pass on a natural gas fired microturbine that would allow the turbine to be used for absorption cooling, space heating and power generation in commercial buildings. A feature that distinguishes microturbines from conventional small gas turbines is the recuperator, a heat exchanger used to pre-heat combustion air with exhaust products.

The project will focus on determining the feasibility of employing the recuperator exhaust by-pass to facilitate the following waste heat applications:

- Absorption cooling.
- Space heating.
- Domestic hot water production.

An adjustable fraction of the microturbine exhaust will be diverted from the recuperator and used to produce a higher temperature waste heat stream. Absorption equipment operating off of the microturbine exhaust without supplemental firing is limited to single effect systems having a nominal coefficient of performance (COP) of 0.6. Raising the temperature by using a recuperator by-pass offers the potential of operating double effect absorption systems having a nominal COP of 1.2.

Proposed Outcomes:

- System design.
- Model of building profiles for energy supply, power demand and thermal demand.
- Economic analysis of the proposed system.
- Feasibility analysis of microturbine exhaust diversion system.

Anticipated Benefits:

- Optimize the energy efficiency of microturbines in commercial building applications which could reduce their energy consumption from the grid by up to 80% by shifting the load to natural gas.
- It is projected that the proposed system could achieve a combined cycle peak efficiency of 85% with an average annual efficiency of 55%.
- Projected payback period is estimated to be between 1.8 and 3.9 years depending on the amount of waste heat that can be utilized.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Modeling of Chemical Processes in Geothermal Reservoirs

EISG Grant Number: 99-25
PIER Area: Renewables
Principal Investigator: Subir Sunyal (510) 527-9876
Organization: GeothermEx, Inc.
Grant Amount: $71,390
Status: Active

Project Description:
The purpose of this project is to research the feasibility of incorporating the recently developed TOUGHREACT code for chemical interactions into the existing TOUGH2 simulation model used for geothermal operations. Geothermal power in California today cannot compete with power from gas-fired plants because of geothermal's higher operations and maintenance (O&M) cost. Geothermal energy's high O&M cost is due in part to the chemical problems related to geothermal fluids: deposition of chemical scales, corrosion, non-condensable gases, etc.

The O&M cost of geothermal electricity could be lowered if these processes could be quantitatively modeled on the computer so that optimized mitigation steps can be taken. Such modeling will also allow enhanced reservoir management, estimation of mineral recovery from geothermal brines, and reduction of environmental impact through minimizing gas emissions by injection optimization. Reduction of O&M cost, enhancement of reservoir management and mineral recovery are all identified as elements of "focus" in the CEC's "Geothermal RD&D Needs and Approaches." The reduction in O&M cost and enhanced reservoir management could save on the order of 0.25 cents/kWh for most projects.

GeothermEx, Inc. proposes to work in collaboration with LBNL to apply TOUGH2 and TOUGHREACT software to solve a set of practical chemical problems encountered in several typical geothermal fields in California. These problems, drawn from published industry experience, would include:

1. Recovery of valuable minerals (such as zinc, silver and manganese) from geothermal brines.
2. Scale deposition around wells.
3. Effects of injecting acidic brine originating from various fluid handling processes.
4. Minimizing gas production through optimized water injection.
5. Modeling of chemically reactive tracer tests to enhance reservoir management.

Proposed Outcomes:

- Produce a comprehensive geothermal model that integrates TOUGHREACT code with the TOUGH2 model.
- Feasibility assessment based on model's ability to perform under real-world conditions.

Anticipated Benefits:

- Reduce the cost of electricity generated by geothermal operations by 25 cents/kWh.
- Optimize mineral extraction strategies for California's high-salinity geothermal reservoirs.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Nanostructured Electrodes for PEM Fuel Cells

EISG Grant Number: 02-28
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Yushan Yan (909) 787-2068
Organization: University of California, Riverside
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using carbon nanotube based electrode catalyst to significantly increase the utilization rate of platinum in the electrodes of proton exchange membrane (PEM) fuel cells. The increase of platinum utilization will lead to reduction of platinum loading, and consequently reduction of cost of PEM fuel cells.

Proposed Outcome:
- A single cell will be fabricated and tested as part of the project.

Anticipated Benefits:
- Proposed technology has the potential to reduce the platinum loading on the electrodes in PEM fuel cells thus reducing their capital cost and thereby lowering the life cycle cost of power ($/kWh).
- Fuel cells in general offer many advantages to include: reduced emissions, higher efficiency, co-generation capability, enhanced grid reliability and elimination of transmission losses.

Project Status:
- Formation of aligned arrays of multiwalled carbon nanotubes – 100%.
- Substrate (carbon paper or cloth) preparation and catalyst (e.g., iron) deposition on carbon cloth or paper – 100%.
- CVD deposition of carbon nanotube films – 100%.
- Deposition of Pt catalyst on carbon nanotubes by electrochemical reduction – 100%.
- Condition screening of electrodeposition of Pt on carbon nanotubes – 100%.
- Electrodeposition of Pt on carbon nanotubes – 100%.
- Fabrication of MEA and single cell – 30%.
- Impregnation of Nafion into the electrode layer and fabrication of MEAs – 100%.
- Fabrication of single-cells and testing – 30%.

New Generation Thermoelectric Materials for Power Generation and Refrigeration

EISG Grant Number: 99-05
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Angelica Stacy (510) 642-3450
Organization: University of California, Berkeley
Grant Amount: $74,994
Status: Active

Project Description:
The purpose of this project is to research the feasibility of fabricating a thermoelectric material into a layer of microscopic unidirectional wires that are oriented perpendicular to the first layer which, in theory, should improve the conversion efficiency of generating electricity directly from heat. Thermoelectric power generators are produced by joining two thermoelectric materials with opposite charge carriers and applying heat to one side. The thermoelectric fabrication is accomplished through the precise, electrodeposition of Cobalt Antimonide ($CoSb_3$) into a porous template. The objective is to produce a higher-efficiency thermoelectric material that can be used in power generation and refrigeration.

Proposed Outcomes:
- Optimized methodology for electrodeposition of $CoSb_3$ in a porous alumina template.
- Assessment of the thermoelectric properties of a fabricated array of $CoSb_3$ nanowires using electrodeposition.

Anticipated Benefits:
- Improve the efficiency of thermoelectric materials above the current state-of-the-art by 10%.
- The advantages of thermoelectric power generation include: no emissions, no moving parts, quiet operation, and it can operate from waste heat.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Draft – Under Review.

New Powerline Control Technology for Lighting and HVAC

EISG Grant Number: 02-26
PIER Area: Energy Systems Integration
Principal Investigator: Marshall Lester (818) 701-9831
Organization: Powerline Control
Grant Amount: $74,318
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of using a new low-cost powerline communications strategy for electrical load control in commercial, industrial and institutional buildings. Given that all electrical loads are linked to the building's grid via power lines, it is intuitively obvious that tremendous electricity cost savings could be derived by utilizing those same power lines to transmit load control signals. Powerline Control Systems (PCS) proposes to conduct research-level analysis, testing and evaluation utilizing that environment as a virtual laboratory. Due to the fact that the actual environment in which any powerline communication method is deployed becomes part of the transmission/receiving circuit, there is no substitute for communication/powerline circuit analysis to determine if the proposed technology will meet the performance and reliability demands of the energy management marketplace.

Proposed Outcome:
- A prototype system will be fabricated and field-tested.

Anticipated Benefits:
- Provide a low cost alternative for implementing load control in the industrial and commercial sectors. Current state-of-the-art systems are too expensive or unreliable in high noise environments.
- Newly constructed commercial buildings with load control have demonstrated electrical savings of 20-45%. Given the retrofit capability of the proposed system, California could save up to 9,000 GWh/year if used just for lighting control (assumes 150,000gWh/year is consumed by commercial/industrial sectors in California, 80% of these buildings do not have load control, 30% of load is from lighting, and that 25% savings could be achieved).

Project Status:
- 100% Complete.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report – Analysis in progress.
- Revised Final Report Draft Submitted.

Novel Approaches to Ignition Enhancement of Natural Gas Under Engine-Like Conditions

EISG Grant Number: 02-11
PIER Area: Energy Systems Integration
Principal Investigator: Fokian N. Egolfopoulos (213) 740-0480
Organization: University of Southern California
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to assess the feasibility of using C_2-hydrocarbons as an ignition enhancer for natural gas under lean burn conditions in an internal combustion engine. These are novel additives, whose use as ignition enhancers has been suggested by investigations of supersonic air-breathing combustion. Compared to hydrogen gas (H_2), C_2-hydrocarbons ignition enhancers are equally clean burning and significantly safer to handle. Their principal advantage, however, lies in their economic production as C_2-hydrocarbons fuels can be produced in situ from natural gas by direct catalytic activation. This project explores this approach for improving natural gas ignition for conditions that are relevant to power generation by internal combustion engines. C_2-hydrocarbons ignition enhancers show significantly more promise than H_2 technology as their production is mature and a technologically feasible process. Enhancing the ignition process of natural gas will significantly impact the power generation industry, and will allow for a more efficient reduction of pollutant emissions.

Proposed Outcome:
- Variations of the proposed ignition enhancer will be formulated and tested as part of the project.

Anticipated Benefit:
- Potential to enable the use of low cost internal combustion engines for base load power generation, which would greatly facilitate and accelerate the implementation of distributed generation infrastructure thereby increasing the reliability and security of the grid.

Project Status:
- Investigate the ignition enhancement characteristics of C_2-hydrocarbons in lean premixed combustion – 95%.
- Evaluate current technologies (Oxidative Coupling of Methane (OCM)) and the economic/technical feasibility of the C_2-hydrocarbon ignition enhancement technology – 75%.

Novel Nanocomposite Carbon Molecular Sieve (CMS) Membranes

EISG Grant Number: 02-17
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Muhammad Sahimi (213) 740-2064
Organization: University of Southern California
Grant Amount: $74,997
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of utilizing novel Nanocomposite mixed matrix membranes in separations of hydrogen and carbon dioxide (CO_2) from binary, ternary, and quaternary gas mixtures of relevance to power generation. These membranes are thought to combine the advantages of polymeric membranes (cheap, easily processed) with the advantages of the molecular sieve membranes (superior separation characteristics). It is believed that these membranes will show superior performance in the various power/energy generation related applications outlined.

Proposed Outcome:
- Nanocomposite mixed matrix membranes will be prepared and tested.

Anticipated Benefits:
- Potential to enable significant progress towards solving the gas separation problem in energy generation systems.
- Potential to reduce CO_2 emissions by effectively separating the CO_2 out of flue gas.

Project Status:
- Preparation of CMS nanoparticles – 75%.
- Preparation of nanocomposite CMS Membranes – 85%.
- Test the transport characteristics of the mixed membranes – 75%.

Plastic Solar Cell

EISG Grant Number: 02-16
PIER Area: Renewables
Principal Investigator: Brian Sager (650) 224-4508
Organization: Nanosolar
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of bench-scale fabrication and characterization of a plastic solar cell based on a new nano-technology. In this project, the team will first optimize the processes for a prototype nanostructured photovoltaic cell. Cell efficiency and stability measurements will form the second task. The final task is an assessment of the materials cost associated with this technology. If feasibility of this approach is proven, then follow on work will optimize the process for efficiency and stability and scale it up to commercial size.

Proposed Outcome:
- A bench-scale nano-structured photovoltaic cell will be fabricated.

Anticipated Benefit:
- Potential to provide a system with a 3kW generation capacity at a savings of 80% over current systems with equal capacity. The cost to the consumer may be one fifth that of conventional technology.

Project Status:
- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Plug-in Photovoltaic Receiver for Concentrator Applications

EISG Grant Number: 99-22
PIER Area: Renewables
Principal Investigator: Pierre Verlinden (408) 991-0910
Organization: SunPower Corporation
Grant Amount: $74,977
Status: Active

Project Description:
The purpose of this project is to research the feasibility of fabricating a standardized plug-in photovoltaic (PV) receiver for Fresnel-lens concentrator systems. High-concentration photovoltaic systems hold the potential to dramatically reduce the cost of PV electricity. By concentrating sunlight with inexpensive plastic lenses, the required area of costly solar cells can be dramatically reduced. In addition, high-concentration PV systems are more efficient compared to conventional flat-plate silicon photovoltaic panels. They can generate about 40% to 60% more energy per unit area on an annual basis.

SunPower Corporation will develop a standardized, highly reliable, plug-in photovoltaic receiver for high-concentration Fresnel-lens systems. The plug-in PV receiver would be factory assembled and would include the following components in a single package: a PV cell, a substrate, a secondary optical element, a bypass diode, a heat spreader and heat sink, plus exterior electrical and mechanical connections. The yearly energy output per unit area of this PV concentrator system is expected to be much greater than a conventional flat-plate silicon module, significantly reducing balance of system (BOS) costs. For moderate volume production, the installed cost of this system will be about $3000/kW, or about half of the cost of today's flat-plate PV systems.

Proposed Outcomes:
- Up to four prototypes receiver units will be built and tested.
- Prototype plug-in PV receiver module.
- Specifications for plug-in PV receiver module.
- Process steps for device fabrication.
- Feasibility assessment based on prototype performance testing.

Anticipated Benefits:
- Reduce the installed cost of fully integrated PV concentrator systems to about $3,000/kW which is less than half the cost of current flat-plate PV systems.
- Increase the performance and reliability of concentrator systems by integrating into a single module under factory controlled conditions: the PV cell, substrate, secondary optical element, bypass diode, heat spreader, heat sink and electrical and mechanical connections.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Pressure Reducing Valve Turbine

EISG Grant Number: 03-08
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Michael Maloney (425) 861-8870
Organization: SOAR Technologies, Inc.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a full-scale power-generating pressure-reducing valve and validating that the air entrapment in the water stream due to the device mechanics is not detrimental to the operation of the water system.

Proposed Outcome:
- A full-scale prototype device will be fabricated and tested as part of the project.

Anticipated Benefits:
- Potential to produce an additional 100,000 kilowatt hour (kWh) per each developed site at $.03/kWh. There are 1000 potential sites in California.
- Proposed technology has the potential to reduce the need for local power utilities to develop additional energy resources thus deferring new plant expenditures, avoiding capital cost, and energy rate increases.

Project Status:
- Design pressure chamber for the turbine – 100%.
- Design test facilities and test plan – 100%.
- Fabricate a full-scale prototype – 100%.
- Finalize test plan – 80%.
- Develop test facilities for prototype – 70%.
- Conduct prototype testing – 80%.
- Conduct manufacturing cost analysis – 10%.
- Conduct life cycle cost analysis – 0%.

Prototype and Demonstration of a Light Emitting Diode (LED) Alternative to Screwbase Incandescent Lamps

EISG Grant Number: 01-03
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Kathryn Conway (518) 331-7236
Organization: Conway & Silver, Energy Associates LLC
Grant Amount: $74,850
Status: Active

Project Description:
The purpose of this project is to research the feasibility of constructing a light-emitting diode lamp with a conventional screwbase and color control capability that could be used in existing incandescent light fixtures. The Contractor will specify and build engineering prototypes, based on U.S. Patent 6,149,283, issued on November 21, 2000, and titled, LED Lamp with Reflector and Multicolor Adjuster.

Proposed Outcomes:
- Fabricate 1 or more LED lamps as funds allow.
- A feasibility analysis based on the performance of the prototype lamps.
- Project objectives are to achieve a minimum 50% improvement in energy efficiency while maintaining light output within 20% of base case incandescent lamps.

Anticipated Benefit:
- LED lamps capable of achieving energy savings of 50% to 70% in light fixtures that would normally use incandescent lamps.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Prototype and Demonstration of Vision-Tuned Fluorescent Lamps

EISG Grant Number: 01-25
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Kevin W. Houser (402) 554-3858
Organization: University of Nebraska, Lincoln
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of developing more energy efficient fluorescent lamps in which a greater percentage of the radiant energy is used to produce light that is optimized for human vision. A significant opportunity exists to optimize light source spectra that will lead to better vision with the minimum expenditure of energy.

The prototype lamps will fully embrace trichromacy of human vision with the goal of eliciting the maximum response from the opponent channels. A minimum of four different types of prototype lamps will be made varying in the degree that they stimulate the opponent channels. Increasing the opponent channel response will be achieved by maximizing radiant energy output in the three spectral regions near 446 nm, 533 nm, and 610 nm while simultaneously minimizing radiant energy in other parts of the spectrum. The prototype lamps will use conventional manufacturing technologies, but will make use of novel phosphor blends designed to regulate the opponent channel responses. This work will pave the way for large scale production of energy efficient vision-tuned fluorescent lamps.

Psychophysical data will be collected during the evaluations and will be used to demonstrate that the prototype lamps are equivalent to, or exceed the performance of, conventional sources along three dimensions critically important to interior working environments:

1. Visual performance.
2. Brightness perception.
3. Color rendering.

Proposed Outcome:

- Prototype lamps will be fabricated and tested as part of the project.

Anticipated Benefits:

- Potential to reduce energy consumption in fluorescent lighting by 20%. There is the potential to save.5 quads with 100% penetration, assuming 2.5 quads of electrical energy are consumed by commercial buildings nationwide.
- Potential to improve lighting quality with resulting benefits in comfort and productivity.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

Quantitative Building Cooling of Tile Roofs Coated with Solar IR Reflective Coatings

EISG Grant Number: 01-20
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Joseph Reilly (714) 680-6436
Organization: American Rooftile Coatings
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of new Infrared (IR) reflective coatings that can be applied to residential concrete or clay tile roofs to achieve a minimum 40% solar reflectance. American Rooftile Coatings is exploring new infrared reflecting architectural coatings for on-site application to steep-pitched concrete or clay tile roofs for the purpose of improving a home's appearance and also reducing its consumption of energy. While flat sloped roofs lend themselves to an easy switch from black to white and subsequent energy savings, steep pitched roofs are more problematic, especially regarding color choice. Aesthetically pleasing colors are important because the roof is about 50% of what one sees from the curb and darker colors are often the choice of a homeowner.

Mixed metal oxide pigments developed for the military in the 1980s demonstrate superior infrared reflectivity. Coatings based on those pigments show improved infrared reflectance in laboratory testing. No conclusive tile roof tests have been published that demonstrate that such IR coatings substantially lower a home's temperature and energy use. American Rooftile Coatings (ARC) has taken a trademark out on COOLTILE IR COATINGS™ with the hope that such coatings will lead to cooler roof temperatures and compete in the cool-roof market place.

The object of this study is to quantify reductions in tile roof temperatures, building cooling power demand and energy usage that is achieved by refinishing roof tiles with IR reflective coatings. American Rooftile Coatings proposes to monitor the roof and interior temperatures of several adjacent pairs of tile-roofed model buildings. The test site will be located in an inland Southern California area to maximize the impact of the power savings in a hot, dry climate.

Proposed Outcomes:
- Produce five experimental IR reflective coatings of different primary colors.
- Create building energy simulation models for collecting temperature data and computing the reduction in cooling power demand and cooling energy usage by applying the IR coatings.
- Produce feasibility analysis based on performance of prototype coatings.

Anticipated Benefits:
- Reduce the cooling load in residential homes with steep-pitch cement or clay tile roofs.
- Reduce roof deck temperature 10-20%.
- Coatings could be used on existing homes as a retrofit product that increases the potential impact of decreased peak load cooling.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Draft – Analysis in Progress.

Radio Frequency Electrostatic Ignition System Feasibility Demonstration

EISG Grant Number: 02-23
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Paul Freen (321) 264-5944
Organization: Eta Tech, Inc.
Grant Amount: $74,998
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a new Radio Frequency Electrostatic Ignition System to reduce nitrogen oxides (NO_x) emissions in natural gas fueled reciprocating engines. Engine performance data to be recorded would include combustion characteristics, knock margin, fuel efficiency, and exhaust emissions. This operational test would also produce valuable mechanical and thermal data so that prototypes for field tests could be designed.

Proposed Outcome:
- A prototype ignition system will be fabricated and tested as part of the project.

Anticipated Benefits:
- Potential to help achieve the targeted fuel-to-electricity efficiency of over 50% in reciprocating engines running on natural gas.
- Potential to help reduce NO_x emissions to 0.01 gm/BHP-hr which exceeds 2007 mandated targets.
- The proposed technology could accelerate the use of low-cost reciprocating engines for base-load power generation in California.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft – in Progress.

Real Time Energy Meter Radio Frequency Communications System

EISG Grant Number: 01-11
PIER Area: Energy Systems Integration
Principal Investigator: Elsmore W. Bush (760) 798-2666
Organization: BCD Electronics, LLC.
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of integrating narrowband VHF radio communications capability with selectable relay control into a DRM-2000 real-time energy meter that will collect, record, and transfer electric meter data to a central location. Real-time electric meters allow utilities to establish an hourly rate structure that discourages usage during more expensive peak usage periods. Leveling peak usage reduces the need for less environmentally friendly generators. It can also provide significant savings to the residential customers.

Expected advantages of the adaptable narrowband VHF over UHF system include the following:

- Under isotropic conditions the VHF has a six-to-one free space range advantage.
- Improved structure penetration.
- Improved terrain following that will result in better coverage and less shadowing.
- Lower parts count insures increased MTBF (mean time before failure).
- Lower cost for parts operating at a six-to-one lower RF frequency.
- The selectable relay control will improve data acquisition reliability.
- Data acquisition time will be reduced as the result of relaying data only where direct data transfers are not possible.
- Improved thru-put by changing relay positions when marginal or varying conditions are encountered.

Proposed Outcomes:

- A prototype real time electric meter with RF communications capability.
- A meter firmware program that incorporates the relay option and avoids energy measurement interrupts during the meter selection interrogations.
- Central control system with RF communications capability.
- Feasibility analysis based on performance of prototype system.

Anticipated Benefits:

- Proposed system offers the potential for low-cost and reliable real-time metering for residential and commercial electrical consumers. This will reduce the cost of meter reading and allow for real-time pricing incentives that will encourage load shifting from peak to off peak.
- Potential to have a real time electronic meter that is cost competitive to the current electro-mechanical meter that sells for $40.
- Potential to provide electric consumers with real-time electrical consumption data that would enable them to manage there power consumption more effectively.

Project Status:

- Printed circuit board layout and fabrication – 100%.
- Order and receive parts – 100%.

- Assemble a meter and bench test the unit – 90%.
- Check output power and receiver sensitivity – 90%.
- Modify meter firmware – 50%.
- Modify base station software – 50%.
- Bench Test Meter System – 0%.
- Field Test Meter System – 15%.

Reduced Cost Power Electronic Converter for Generator Applications

EISG Grant Number: 99-23
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Herbert Hess (208) 885-4341
Organization: University of Idaho
Grant Amount: $74,977
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing a more efficient and lower cost power-electronic converter for use in variable speed electrical generation applications such as wind and water turbines or gas microturbines. The following three concurrent and innovative changes are proposed:

1) Reduce the number of power switching devices by half.
2) Develop a new modulation algorithm that takes advantage of common, but usually neglected filtering properties of the induction machine.
3) Configure a simple filter topology to capture the energy produced by the system.

The modified system has the following advantages over conventional variable-speed wind-turbine induction-motor systems:

- Approximately half the capital cost of the power electronic converter.
- Retains the advantages of variable speed operation without modification to the generator itself.
- Energy savings come from reduced line losses and improved ability to operate the load nearer its optimum power output and efficiency.
- Improved system performance, particularly in the case of generating behind long radial lines with a controllable source of both real and reactive power having very low harmonic content to enhance clean, stable operation usable as is for variable speed conversion capability for any turbine generator, such as hydro, gas microturbines, etc.

Proposed Outcomes:

- A prototype converter will be fabricated and tested.
- Prototype power converter rated for15 horsepower.
- Control algorithm for the direct-current bus.
- Feasibility assessment based on prototype performance testing.

Anticipated Benefits:

- Reduce by 50% the capital cost of power electronic converters for variable speed applications.
- Enable turbines to operate at their optimum power output and efficiency.
- Save energy by reducing line losses.
- Eliminate need to modify the generator for variable speed operation.

Project Status:

- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Research Energy Efficient Designs for Swimming Pool Pump Systems

EISG Grant Number: 00-08
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Taghi Alereza (916) 363-8383
Organization: ADM Associates, Inc.
Grant Amount: $74,691
Status: Active

Project Description:
The purpose of this project is to research the feasibility of reducing the flow rate of the filter pumps on commercial and educational swimming pools while maintaining the required water quality. In educational and commercial facilities with swimming pools, it is often standard practice to run the pumps for the pool filtration system continuously at the design flow rate. Because swimming pools in educational and commercial facilities are generally not open 24 hours a day, there is room to reduce the flow rate of the filtration system pump during those hours when the pool is not in use. The question at issue is how much the flow rate can be reduced during hours when the pool is not actually being used without compromising the water quality needed for health reasons. Various aspects of water quality will be monitored, including the following:

- Turbidity or clarity of the water.
- pH level (which needs to be maintained between 7.2 and 8.0).
- Free chlorine residuals.
- Bacteriological quality of the water.
- Chemical quality of the water.

Proposed Outcomes:

- Optimized energy efficient strategy for operating swimming pool filter pumps.
- Feasibility analysis based on performance of modified pump operation at test sites.

Anticipated Benefits:

- Estimated energy savings of 20,000 kWh per year per pool based on a 25% deduction in flow rate for 8 hours per day.
- Potential to save 840 MWh per year in California from approximately 40,000 candidate pools.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Research on Manufacturing Quadruple-Junction Solar Cells

EISG Grant Number: 00-14
PIER Area: Renewables
Principal Investigator: Robert Hicks (310) 825-8891
Organization: University of California, Los Angeles
Grant Amount: $74,268
Status: Active

Project Description:
The purpose of this project is to research the feasibility of increasing the conversion efficiency of quadruple-junction solar cells by optimizing the chemical vapor deposition process. Quadruple-junction solar cells show great potential for achieving terrestrial conversion efficiencies above 40%. At these levels, the photovoltaic devices could be competitive for large-scale electric power generation. Quadruple-junction solar cells consist of epitaxial thin films of indium, gallium phosphide (Ino.48Gao.52P), gallium arsenide and indium gallium arsenic nitride (Ino.o9Gao.91ASO.97NO.03) lattice-matched to germanium substrates. A sophisticated chemical process known as metalorganic chemical vapor deposition (MOCVD) produces these materials.

The objective of this project is to identify the MOCVD process conditions crucial to the development of a robust manufacturing technology. This technology must be capable of producing defect-free films with sharp interfaces and precise composition profiles. The atomic and microscopic structures produced by MOCVD will be characterized by scanning tunneling microscopy, x-ray photoemission, spectroscopy, high-resolution x-ray diffraction, photoluminescence, and current-voltage measurements. New deposition process will be developed and examined for the fabrication of quadruple-junction solar cells with light conversion efficiencies exceeding 40 percent.

Proposed Outcomes:
- Methodology for vapor deposition process that yields precise smooth layers with sharp interfaces between layers.
- Feasibility analysis based on performance of fabricated test samples.

Anticipated Benefits:
- Solar power production at a cost of $.03-$.04 kWh.
- Achieve solar cell conversion efficiency over 40%.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Sealing and Contacting to Novel Integrated Solid Oxide Fuel Cells

EISG Grant Number: 02-01
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Scott Barnett (847) 491-2447
Organization: Northwestern University
Grant Amount: $74,954
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of using metal brazing alloys for sealing and the electrical contacts within a novel type of solid oxide fuel cell. The basic technical feasibility of the integrated solid oxide fuel cell (ISOFC) has been demonstrated recently, so the main feasibility issues remaining are sealing and electrical contacts. The proposed innovation here is to use metallic alloys both for making gas seals and electrical contacts to the fuel cells.

The specific objectives are to determine the feasibility of this approach, to determine the optimal materials and processing procedures, and to fabricate prototype ISOFC stacks complete with seals and contacts, and demonstrate effective performance of the stacks.

Proposed Outcome:
- Complete integrated solid oxide fuel cell stacks using metal brazing for sealing and contacting will be fabricated and tested.

Anticipated Benefits:
- Potential to accelerate the development of fuel cell technology to achieve the cost and reliability needed in order to be used in distributed generation applications.
- Fuel cells offer the promise of reduced emissions, higher efficiency, increased grid reliability and increased grid power.

Project Status:
- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft – in Progress.

Self-Optimized Controllers for Air Conditioners

EISG Grant Number: 02-25
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: T. S. (Jay) Jayadev (408) 257-6465
Organization: Energy Savers International
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to determine the feasibility of developing a low-cost self-optimizing controller for single-phase air conditioners that reduces electrical consumption by 20%. There is an equal amount of energy that can be saved in the light commercial sector. These energy savings can result in a proportionate decrease of pollutants released into the atmosphere by fossil-fuel burning power plants.

In a retrofit situation, the component performance characteristics and system behavior are not well defined, unlike the situation with the design of new units. The proposed self-optimizing technique intends to overcome this obstacle of insufficient information to operate the air conditioner at optimum efficiency in retrofit applications.

Proposed Outcome:
- A prototype controller will be fabricated and tested as a retrofit unit on a conventional 3-ton air conditioner.

Anticipated Benefits:
- Potential to significantly reduce peak electrical demand caused by air conditioners.
- Potential to save up to 5,000 GWh/year in California based on just residential air conditioner and heat-pump savings (assumes 20% energy saving and 100% market penetration). An equal amount could also be saved in light commercial applications.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Draft – Analysis in Progress.

Single Crystal Silicon Sheet Growth

EISG Grant Number: 00-02
PIER Area: Renewables
Principal Investigator: Carl Bleil (248) 370-3406
Organization: Energy Materials Research
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of producing single crystal sheets of semiconductor quality silicon directly from a polycrystalline source at a minimum production rate of 35 cm/min up to a maximum of 350 cm/min using an advanced horizontal ribbon growth (HRG) method. The patented approach presented here and validated in the laboratory addresses the critical control features of a modified HRG process necessary to realize the continuous growth of single crystal silicon sheets. A unique concept invoking capacitive coupling of radio frequency (RF) power to the silicon sheet seed is employed. When properly applied in a uniform thermal environment, it allows disturbances at the nucleating tip and at the exit solid-liquid phase boundary to be eliminated. The problems of maintaining a uniform thermal environment, controlling temperature gradients, and preventing polycrystalline nucleation are resolved. The process permits the stable growth of the silicon sheet to be controlled electrically, making the HRG method a practical process.

Proposed Outcomes:
- Prototype Horizontal Ribbon Growth processor.
- Production methodology.
- Technical and economic feasibility analysis of proposed methodology.

Anticipated Benefits:
- 50% reduction in the energy consumed to produce quality silicon sheet.
- 40% reduction in the material losses associated with producing single crystal sheets.
- Potential 50% capital cost reduction of electronic grade silicon sheets.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Solid State Electrolyte for Dye-Sensitized Solar Cells (DSSCs)

EISG Grant Number: 01-24
PIER Area: Renewables
Principal Investigator: Russell Gaudiana (978) 654-6961
Organization: Konarka Technologies, Inc.
Grant Amount: $74,735
Status: Active

Project Description:
The purpose of this project is to research the feasibility of using a specially formulated gel as an electrolyte in dye-sensitized solar cells (DSSCs) that permits effective encapsulation in the manufacturing process. Our specific project goal is to develop a solid-state electrolyte that outperforms the liquid electrolytes presently used for DSSCs, and would represent a significant advance. Konarka Technologies' proposed research has three key objectives:

1. Develop an electrolyte gel that can be transitioned from liquid to solid at temperatures ranging from 40-90ºC, without compromising its performance.
2. Eliminate volatiles from the coating solvents and active components.
3. Achieve cell performance equal to or better than that of liquid electrolytes.

Proposed Outcome:

- Prototype solar cells will be fabricated and tested as part of the project.

Anticipated Benefits:

- Potential to reduce the manufacturing cost of solar cells to less than $1/peak watt (Wp) through low cost materials and roll-to-roll manufacturing.
- Low cost thin film PV would significantly expand the cost effective applications for PV in California.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Steady State Security Assessment of Deregulated Power Systems

EISG Grant Number: 02-05
PIER Area: Energy Systems Integration
Principal Investigator: Elham B. Makram (864) 656-3378
Organization: Clemson University
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of a computational strategy for rapidly assessing the state of the transmission network following possible system contingencies, and would determine post-contingency power flow, bus voltages and loading margins.

With the inception of deregulation, transmission networks are subjected to a host of bilateral transactions, which would influence physical system quantities like real power flows, security margins and voltage levels. For efficient asset utilization and maximization of the revenue, more often than not, transmission networks are operated under stressed conditions, close to security limits. Therefore, a quantitative assessment of the extent to which each transaction adversely affects the transmission network is required. This needs to be done accurately as the feasibility of the power transactions and subsequent decisions (execution, curtailment, pricing) would depend upon the outcome of the analysis. Also considering the large number of transactions occurring in the power market and the massive sizes of transmission networks, the need for efficient analysis techniques is further highlighted. Thus on the whole, for present-day power systems, security assessment has acquired predominant importance.

Proposed Outcome:
- A voltage instability indicator and distribution factors using the Jacobian matrix will be developed and utilized.

Anticipated Benefits:
- Potential to enable the electrical utility to accurately and quickly assess the various state variables of the transmission networks following contingencies that would allow mitigating actions to be taken to ensure the reliability of the system.
- Potential to support the deployment of distributed generation resources by allowing the electrical utility to assess the impact specific distributed generation systems would have on the transmission network if they were brought on line.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Report Draft – Analysis in Progress.

Test Program for High Efficiency Turbine Diffuser

EISG Grant Number: 01-29
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Thomas Norris (415) 391-2158
Organization: Consultants in Engineering Acoustics
Grant Amount: $74,220
Status: Active

Project Description:
The purpose of this project is to research the feasibility of reducing backpressure on turbines designed with a right angle bend in the outlet by inserting aerodynamic vanes and devices placed inside the exhaust diffuser. The project will demonstrate the viability of a concept previously developed on a small-scale model of a power generation combustion turbine. The application is for gas turbines that have a right angle bend in the exhaust just downstream of the exhaust diffuser. The exhaust diffuser is an aerodynamically shaped duct section located just downstream of the last turbine wheel. An excellent diffuser will improve power and efficiency. The goal is to increase combustion turbine efficiency and power by one percent in most turbines with a right angle bend and by two percent in an older turbine model that is now being remanufactured and installed for peaking purposes. Fuel use is not increased.

Proposed Outcome:
- A larger turbine exhaust scale model and fan system to replace the present 1/8-size model will be fabricated and tested as part of the project. The expected scale factor is1/4 to 1/3.

Anticipated Benefits:
- Potential to increase gas turbine efficiency by 1% at little additional cost thereby reducing the cost of power from gas turbines.
- Large potential retrofit market for turbine installations with right angle bends after the exhaust diffuser.

Project Status:
- Build Scale Model – 100%.
- Install Flow Measurement Instruments – 100%.
- Build and Install Flow Improvement Devices – 50%.
- Obtain Flow/Pressure Measurements – 0%.
- Calculate Fuel Savings – 70%.

The Sagebien Project

EISG Grant Number: 00-24
PIER Area: Renewables
Principal Investigator: Richard Ely (530) 753-0562
Organization: Davis Hydro
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing an undershoot water wheel modified to allow for fish passage. Turbines and their associated diversion dams form direct barriers to fish migration up and down stream causing mortality and morbidity of species that pass them. Common low-head diversion dams are open channel flows. Water wheels allow fish to pass effortlessly down stream, but challenge fish moving upstream except during floods. One type of water wheel, the undershot breast wheel – and the Sagebien Wheel in particular – might be modified to allow fish to pass both ways and still efficiently generate hydropower.

Proposed Outcomes:
- Functional prototype of a modified water wheel to allow for fish passage.
- Demonstrate that a useful amount of power can be generated from the given design.

Anticipated Benefits:
- Fish friendly hydropower plant allowing upstream and downstream fish passage.
- Easy adaptability to changing conditions.
- Efficient power extraction.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report – Analysis in Progress.

The Use of Solid Oxide Membranes in Power Generation Applications

EISG Grant Number: 99-32
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Theodore Tsotsis (213) 740-2069
Organization: University of Southern California
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to evaluate the technical feasibility of using the waste heat in the exhaust stacks of power generating equipment to decompose carbon dioxide (CO_2) through the use of solid oxide membranes and to then mix the decomposed elements (carbon monoxide (CO) and oxygen (O_2)) into the fuel stream to augment combustion thereby increasing thermal efficiency. The key objective of the proposed work is to evaluate technical feasibility, environmental implications, and long-term economic viability of a novel technology that improves electric power generation efficiency while simultaneously providing an avenue for CO_2 sequestration.

The technology combines direct thermal CO_2 decomposition with an advanced power generation concept involving waste heat utilization and integration by chemical recuperation, otherwise known as the CRGT cycle. More specifically, a high-temperature asymmetric solid-oxide membrane reactor technology will be developed that will allow for the direct thermal CO_2 decomposition into CO and O_2, while simultaneously utilizing waste heat in the context of power generation. The feasibility study will first focus on the choice and testing of the appropriate membrane material. Subsequently, the combustion characteristics of the resulting fuel blends of methane, carbon monoxide, carbon dioxide, oxygen, and nitrogen will be systematically quantified since their combustion characteristics have not been studied systematically studied in the past.

Proposed Outcomes:
- Membrane technology that will be appropriate for the direct thermal decomposition of CO_2.
- Quantification of the combustion characteristics of fuel blends of methane, carbon monoxide, carbon dioxide, oxygen, and nitrogen.
- Feasibility assessment based on the prototype membrane and combustion testing.

Anticipated Benefits:
- Reduce the cost of power generation in systems that utilize combustion by using the waste heat to improve thermal efficiency or by selling the decomposed elements (CO and O_2) to partially offset the cost of generation.
- Reduce CO_2 emissions and enable CO_2 sequestration if desired.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted – Under Review.

Ultra Reduced Emissions Burner for GTCC and CHP Applications

EISG Grant Number: 01-15
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: John T. Kelly (408) 982-2302
Organization: Altex Technologies Corporation
Grant Amount: $74,933
Status: Active

Project Description:
The purpose of this project is to research the feasibility of a duct burner design for gas-turbine combined-cycle systems that can divide the flame into several zones thereby allowing better control of flame stability, CO emissions and NOx emissions. Altex Technologies Corporation has identified a duct burner concept called the Ultra Reduced Emissions Burner (UREB). It can produce stable flames and very low NOx emissions. This can be accomplished because the burner divides the flame into several zones that are able to balance the usually conflicting requirements of flame stability, flame quality, CO and NOx emissions. Conventional duct burners using a single flame zone makes it impossible to optimize all of the flame qualities mentioned. Preliminary calculations and tests suggest that the fully-developed UREB may be able to lower NOx to 1ppm at 15% O_2.

Proposed Outcomes:
- A prototype duct burner that achieves 2ppm NOx and 6ppm CO at 15% O_2.
- Feasibility analysis based on performance of prototype system and economic evaluation.

Anticipated Benefits:
- Potential to reduce the cost of power from gas turbine combined cycle systems by reducing or eliminating the need for expensive post combustion NOx controls.
- Potential to reduce the cost of NOx removal by 90% relative to Selective Catalytic Reduction (SCR) technology.
- Estimate potential savings of $29 Mil/year from GTCCs and an additional $63 Mil/year if used in combined heat and power (CHP) system.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Independent Assessment Report Draft – in Progress.

Unified Power Quality Conditioner Using One-Cycle Control

EISG Grant Number: 02-07
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Keyue Smedley (949) 824-6710
Organization: University of California, Irvine
Grant Amount: $75,000
Status: Active

Project Description:
The purpose of this project is to demonstrate the feasibility of using the applicant's patented One-Cycle Control (OCC) circuit design to simplify and reduce the cost of a Unified Power Quality Conditioner (UPQC) that can compensate for reactive power flow, harmonic distortion, and voltage variation/sag. UPQC is a device that is connected in the utility side of the substation to control power flow, regulate the voltage against sag/swell, and eliminate harmonic and reactive current. It is an indispensable element for distributed power generation. The proposed UPQC functions has variable impedance. The value and phase of this impedance can dynamically adjust to steer the power flow to the right direction as well as regulate the voltage while the frequency characteristics can be adjusted so that the impedance to harmonics is maximized to resist harmonic current flow.

Proposed Outcome:
- A 5 kilowatt three-phase bench-scale prototype of One-Cycle Control Unified Power Quality Conditioner (OCC-UPQC) will be fabricated and tested.

Anticipated Benefits:
- Potential to reduce California electrical consumption by 10% if installed in 50% of the utility electrical substations.
- May increase the capacity of the California transmission system by 5%.

Project Status:
- Simulation, Equipment Preparation – 100%.
- Schematic Circuit Design – 100%.
- Prototype Fabrication – 100%.
- Debug and Test – 80%.

Use of Waste Fuel Gas to Reduce Biofouling of Power Plant Cooling Water Intakes

EISG Grant Number: 01-08
PIER Area: Environmental Area
Principal Investigator: Greg Rau (925) 423-7990
Organization: University of California, Santa Cruz
Grant Amount: $74,814
Status: Active

Project Description:
The purpose of this project is to research the feasibility of injecting a small amount of flue gas from a gas-fired power plant into the cooling water intake to serve as an anti-biofouling agent for the power plant cooling water intake surfaces. The colonization of cooling water intakes by biota significantly impedes water flow, increases parasitic power requirement for pumping such water, and reduces cooling efficiency when biota become lodged in condenser tubing. The present prevention/remediation of this problem includes the periodic addition of bleach to the intake water, closed-cycle heating of the water, and plant shutdown to facilitate intake drainage and physical removal of biota from intake surfaces. Various other chemical additives and pipe coatings are being used in the power industry, but these are usually expensive, have limited lifetimes, and can have environmental impacts.

Significant reductions in the growth rate of marine biota of the type that contribute significantly to biofouling are achieved by an increase in the concentration of a certain, otherwise innocuous seawater constituent. Since one source of this constituent is contained in flue gas from energy generation, it is suggested that the continuous addition of a small fraction of this byproduct into intake water could significantly reduce settling and growth of such organisms. If effective, such procedures would reduce or possibly eliminate the costly and potentially hazardous biofouling treatments currently employed. A series of on-site tests will be conducted at the Duke Energy's power plant at Moss Landing, California to determine the efficacy of such an approach.

Proposed Outcomes:
- A laboratory scale test rig will be constructed on site.
- Feasibility analysis based on the performance of the laboratory scale system.
- Optimized strategy for delivery and dosing levels.

Anticipated Benefits:
- Replace the costly and environmentally harmful biofouling treatments currently employed with the proposed system that would be lower cost and less harmful to the environment.
- An anti-biofouling agent that meets or exceeds all water quality regulations.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Independent Assessment Report Draft – in Progress.

Ventilation Cooling Controller Strategies

EISG Grant Number: 99-28
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Murray Milne (310) 454-7328
Organization: University of California, Los Angeles
Grant Amount: $74,895
Status: Active

Project Description:
The purpose of this project is to research the feasibility of developing an intelligent natural-ventilation cooling controller that can determine and implement the most efficient strategy for pulling in outside air to reduce air conditioning costs in residential homes. The greatest potential source of cooling energy in most California climates is cool outdoor air when available to flush overheated buildings. In most California climate zones nighttime temperatures are usually quite comfortable. The controller's task is to know how much night-time air should be brought in to cool down the building's interior mass so that it can 'coast' comfortably through the next day, and not overcool it to the point that heating is needed the following morning. This controller should also know if it is using more fan energy then it is recovering in cooling, or if wind-driven natural ventilation is available. Our studies have shown that the need for air conditioning can often be completely eliminated in many climates if the building is carefully designed and if a smart controller can be developed to harvest this resource.

Proposed Outcomes:
- Prototype ventilation cooling controller with control logic designed for the 16 climate zones in California.
- Feasibility assessment based on prototype performance testing in large-scale test cells.

Anticipated Benefits:
- Eliminate or reduce the need for air conditioning in California climate zones that have cool nighttime temperatures.
- Achieve minimum energy savings of 100,000 megawatt hours per year in California if the technology eliminated the need for one out of every thousand air conditioners.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Draft Final Report Submitted.
- Feasibility Analysis Report Drafted.
- EISG Program Administrator's Review of Final Report Draft in Process.

EISG Projects Completed in 2004

A New Gas Turbine Engine Design for Electricity Generation with Increased Efficiency & Power

EISG Grant Number: 99-09
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: William Sirignano (949) 824-3700
Organization: University of California, Irvine
Grant Amount: $75,000
Status: Active

Project Description:
Most of the new electrical generators installed in California are large (>50 megawatt (MW)), gas-fueled combustion turbines. A small increase in the efficiency beyond that of those turbines would have a major, positive impact on the price and availability of electricity on the California market.

This project investigated the potential of a new gas turbine cycle that the researcher named the "turbine-burner." In this cycle heat is added to the turbine gas flow using a conventional combustion system, and additional heat is added to the turbine gas flow by combustion inside the turbine itself. The researcher investigated both continuous stage-to-stage combustion (CTB) and discrete inter-stage burners (ITB). The ITB concept is similar to the inter-stage combustor found in the commercial Alstrom GT 24 gas turbine engine. There are two major benefits to sequential addition of fuel to a combustion turbine. First, the temperature of the gasses entering the next turbine stage is at the highest safe level, protecting the turbine while offering the greatest energy transfer to the turbine. Second, the energy in the compressed gasses is almost fully exploited by burning out nearly all of the oxygen in the air.

Further, this project investigated the effects of combining heat regeneration with continuous and discrete inter-stage combustion, and this was the principle focus of the analysis. Regeneration is the process of recovering heat from the exhaust gasses and transferring that heat to the high-pressure air exiting the turbine compressor. Solar Turbines Inc. has recently developed a 4.5 MW gas turbine with a regenerator. Micro-turbine manufacturers also offer regenerated engines. None has combined the regenerator and inter-stage combustor features into one engine model.

The researcher claims that the proposed cycle offers the potential to increase gas turbine thermal efficiency to a theoretical 65%, and to double the power density of the existing engines. Heat regeneration has a significant effect on the cycle efficiency, while inter-stage combustion increases the power density. The proposed engine is a recuperated engine with inter-stage burners. It is not a combined cycle gas turbine. Today's best combined-cycle gas turbines are approximately 60% efficient.

Proposed Outcomes:
The goal of this project was to determine the feasibility of implementing continuous combustion in the turbine section of a gas turbine combined with heat regeneration to increase thermal efficiency to the 65% level. The researcher established the following project objectives:

1. Determine the optimum design configuration for a gas turbine with continuous combustion and a regenerator. Perform detailed cycle analysis of several design concepts. Optimize the design by varying engine parameters such as turbine inlet temperature, pressure ratio and power distribution in the turbine stages.
2. Develop engine design tools using aero-thermodynamic and combustion analysis to evaluate the effects of continuous, in-stage combustion flow in the turbine section.

3. Calculate theoretical efficiency and power density for an engine with continuous combustion.

Actual Outcomes:

1. The project developed a computer code for the analysis of turbine cycles with inter-stage and continuous (in-stage) combustion. The researcher identified preferred design configurations.
2. The researcher developed a computational method and code for the compressible Navier-Stokes equations with multiple species and chemical reactions. Using this code the researcher studied a two-dimensional diffusion flame in a transonic flow with large stream-wise and transverse pressure gradients typical of conditions in a turbine passage.
3. The researcher calculated theoretical efficiencies and power densities.

Conclusions:

1. The project found that the discrete inter-stage burner (ITB) cycle is a good intermediate solution before the technological challenges of the continuous turbine-burner cycle can be resolved. Direct combustion in the turbine section can lead to material failures if the ignition, flame-holding and control techniques are not properly developed.
2. The researcher determined that ignition and flame-holding in the turbine passage under conditions of high acceleration of the flow is possible for methane/air mixtures when the incoming air is sufficiently heated.
3. The theoretical maximum efficiency is 65%. The best power density is approximately 2.5 times that of an engine with a single traditional combustor. These numbers represent best theoretical values and may not be achievable in practice.

The researcher has established the theoretical feasibility of the ITB and CTB concepts using analytic modeling as originally proposed. In addition the researcher has identified several issues for further research. These include studies of combustion in a turbine passage, ignition and flame holding methods, and the development of a large eddy simulation code. The Program Administrator identified several practical obstacles that could impede the progress toward a physical realization of the CTB concept. These include materials challenges in the turbine section, durable high-temperature regenerators, high-effectiveness regenerators, sensors and controls for the continuous burning section, controls for load following, and manufacturing problems associated with a rather complex system. These many issues remain to be addressed through follow-on RD&D.

The major contributions of this research are the analytical tools and models developed to study combustion within the turbine section of the engine. In addition, the concepts developed in this project are better suited to combustion turbines less than 50 MW. The size and cost of regenerators will limit the size of regenerated, combustion turbines. If the proposed concepts can be commercialized, the resulting combustion turbines will be highly efficient offerings in the distributed generation market.

Turbine design engineers are very conservative because their customers demand very high reliability. The gas turbine industry may adopt the concepts developed in this project, but at a very measured pace. The Alstrom GT24 already employs one inter-stage combustion chamber that approximates the ITB concept described by the researcher. Other manufacturers have offered regenerated engines.

Benefits to California:
This project provides the theoretical background for a combustion turbine system with increased efficiency and power density. Many technical hurdles stand between the concept and a practical turbine engine. For this reason California will only realize benefits after a significant amount of applied research and development. The Program Administrator estimates that this line of research might provide ratepayer benefits in the 2017 to 2022 timeframe. The project concept, if successful, will reduce fuel consumed to produce electricity and could significantly lower the initial capital cost of a turbine generator.

Recommendations:
The Program Administrator recommends that the researcher engage a gas turbine manufacturing company in the evaluation and development of the CTB concept. The manufacturer must develop an engineering development plan utilizing the researcher's concepts before further study should begin. Significant additional research is required before commercial application of these concepts can occur. Thus, the researcher should seek follow-on funds from institutions that focus on basic research to reduce the perceived level of risk. The addition of a gas turbine manufacturer to the research team could significantly reduce the time required to bring this technology to the market.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

An Integrated Anti-Fouling Technology for Energy Efficient Chillers

EISG Grant Number: 00-23
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Young Cho (856) 424-8118
Organization: J&D Thermo-Fluid Technology, Inc.
Grant Amount: $74,953
Status: Completed

Project Description:
Chillers are major energy-consuming devices in large commercial and institutional buildings in California. They provide chilled water in central-air-conditioning systems in schools, hospitals, public and commercial buildings, and in industrial process equipment. The electricity consumed by medium-to-large chillers (200–2,000 tons) ranges from 0.25 kilowatt (kW)/ton to 0.57 kW/ton, at 40% and full load respectively. A 2,000-ton system, operating at full load on a hot afternoon, will consume over one megawatt-hour per hour. Fouling of condenser tubes decreases chiller efficiency dramatically. To limit fouling, water in the cooling tower is drained to carry away the concentrated mineral salts, and fresh water is introduced. Fouling still occurs and results in increased electricity consumption. This is particularly serious on hot afternoons in California, when air conditioning consumes 30% of all electricity.

If the method studied in this project can alleviate the problem of fouling of the condenser tubes, chillers will run more efficiently during the entire cooling season, resulting in substantial and continuous savings in electricity. Increasing the efficiency of cooling systems will reduce the peak demand for electricity during the hottest days of the year and save a substantial volume of water.

This project studied a unique, electromagnetic precipitation and filtration method to prevent or mitigate fouling in chiller condenser tubes. It is based on two technologies: solenoid-induced precipitation and side-stream filtration. Solenoid-induced precipitation utilizes a square-wave pulsating current to create time-varying magnetic fields. The magnetic fields then produce an induced, pulsating electric field in the circulating water. The electric field causes excess mineral ions such as calcium and magnesium in cooling-tower water to precipitate as mineral salts. These salts provide nucleation sites for other dissolved mineral ions. As the cooling-tower water continuously circulates, the precipitated seed crystals grow into larger particles that are removed by side-stream filtration. Removal of scale-causing mineral ions from cooling-tower water prevents or significantly mitigates fouling at the condenser tubes, resulting in direct electricity savings. The removal of mineral ions by the side-stream filtration system also permits an increase in the concentration cycle of the cooling water (the time period between replacements of the cooling water) resulting in substantial water savings.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using solenoid-induced precipitation and side-stream filtration to maintain 90% heat-transfer efficiency of chiller condensers by limiting scale deposits on the condensers. The researchers established the following project objectives:

1. Fabricate a prototype system using both solenoid-induced precipitation and side-stream filtration for medium-to-large chiller applications, (greater than 200 tons).
2. Demonstrate that this technology can limit scale deposits to maintain 90% heat-transfer efficiency using a concentration cycle of five.

3. Demonstrate that this technology can limit scale deposits to maintain 90% heat-transfer efficiency using a concentration cycle of eight.

Actual Outcomes:

1. The researcher constructed a test-flow loop that consisted of a laboratory cooling tower, heat-transfer test section, an automatic blow-down system, a flow meter, solenoid-induced precipitation, and side-stream filtration.
2. The researcher conducted fouling tests using a high heat flux of 90-100 kilowatt/square meters (m^2) in order to accelerate the fouling process, a practice common among fouling researchers. Controls limited variation of the electric conductivity of circulating water in the simulated cooling tower to within 5% of the set conductivity value. A solenoid valve controlled the blow-down using input from the electric conductivity meter. This test ran for five cycles of concentration. The heat transfer coefficient remained above 90% for 150 hours with no detectable trend to lower values.
3. The test procedure used for eight cycles of concentration was similar to the above. In this test the heat-transfer coefficient remained above 90% for 150 hours, with no detectable trend to lower values. In a control test, the heat-transfer coefficient dropped below 90% after about 50 hours and displayed a marked downward linear trend thereafter.

Conclusions:

1. This project successfully constructed an experimental apparatus to test the feasibility of the method.
2. The heat-transfer coefficient remained above 90% for 150 hours and five cycles of concentration.
3. The heat-transfer coefficient remained above 90% for 150 hours and eight cycles of concentration.
4. Particulate matter captured in the side-stream filter caked into a hard substance during the test. Continued operation would result in an inoperable filter. Some back-washable filters are designed specifically to reduce the accumulation of calcium carbonate scale crystals so that the scaling is minimized and does not become a problem. It is recommended that tests be done to verify the benefit of these filters when operating specifically in the conditions created by the use of this method.

Based on findings in this project, chiller condensers equipped with a device incorporating this method could be operated within 10% of maximum peak performance. This could result in significant energy savings for operators of medium-to-large chillers. The present project demonstrated the feasibility of integrated anti-fouling technology.

Benefits to California:

The heat-transfer performance of a water-cooled chiller degrades as the condenser tubes become fouled. As the fouling decreases the efficiency of the chiller, energy consumption increases. Typically, a large chiller consumes 0.6 kW/ton when its condenser tubes are clean free of and scale. When the condenser tubes become fouled, the chiller runs at a level substantially greater than 0.8 kW/ton. The cost of correcting this problem is relatively small compared to increased energy costs due to fouling in the condenser tubes. If the results from the project are widely used in California, water-cooled chillers can be operated near initial peak efficiency. Ratepayers who operate large chillers will be the primary beneficiaries. Other ratepayers will benefit from the decreased load on the grid during peak summer hours, when air conditioners are widely used.

Recommendations:
The manner in which particulates are filtered from water remains a technical challenge for this project that must be solved prior to commercialization. Calcium carbonate and other crystals accumulated at the top of the filter medium, caking into a hard substance over time. The researcher must redesign the filter to avoid caking of calcium carbonate scale crystals. Some filters are designed to be back-washed to reduce the accumulation of materials. Other solutions should also be investigated. Once that problem has been overcome, the researcher should work directly with a commercial chiller manufacturer. That work should entail integration into standard commercial products and a field test of prototype units.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Composite Architectures for Sub-600C Solid Oxide Fuel Cells

EISG Grant Number: 99-35
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Lutgard De Jonghe (510) 486-6138
Organization: University of California, Berkeley
Grant Amount: $70,811
Status: Completed

Project Description:
Fuel cells incorporating a stack of solid oxide membranes can be highly efficient and environment-friendly systems for electrical power generation. Their broad implementation is, however, hindered by high capital costs and by performance issues that arise when low-cost configurations are contemplated. An essential characteristic of solid oxide fuel cell systems that can solve the cost problem is operation at temperatures much below the current operational domain of 850-1000^{0}C. Significant reduction in temperature creates the potential for the use of low-cost materials for metallic interconnects, fuel cell membrane support structures, and sealing. This project targeted an important technical issue that limits the effective functioning of low-cost solid oxide fuel cells: offsetting the decreased electrode activity that accompanies reduction in temperature. This project addresses the PIER subject area of Environmentally Preferred Advanced Generation.

This project studied the feasibility of configuring novel composite architectures for solid oxide fuel cells targeted for operation at or below 600^{0}C. It addressed the issue by formulating and characterizing composite electrodes functioning in laboratory cells between 550 and 700 ^{0}C.

The project led to the formulation of solid oxide fuel cell membrane assembly configurations and compositions, incorporating novel composite electrodes that can be expected to offer significant improvements over existing approaches.

Proposed Outcomes:
The goal of this project was to determine the feasibility of operating composite fuel cell membranes efficiently at 600^{0}C and below, while achieving an overall membrane area resistance of less than 1 Ohm-cm^2 at these low temperatures. The following project objectives were established:

1. Develop a fuel cell membrane utilizing low-cost colloidal techniques in the manufacture of the cell.
2. Develop a multilayer cathode supported fuel cell structure.
3. Measure cell performance, including membrane area resistance, at temperatures of 550 to 700ºC using both galvanostatic techniques and electrochemical impedance spectroscopy.
4. Develop a high performance multilayer cathode structure on an anode supported Yttria Stabilized Zirconia (YSZ) or Scandia Stabilized Zirconia (SSZ) electrolyte.
5. Develop a method for optimizing fuel cell electrodes at different temperatures.

Actual Outcomes:

1. The project formulated a novel solid oxide fuel cell membrane composite architecture.
2. The cathode supported membrane contained pinholes. It was estimated that insufficient time was available to develop a technique that would not result in pinholes on the membrane. As a consequence, an anode supported fuel cell structure was introduced as objective 4.

3. The cathode consists of a dual layer of Lanthanum Strontium Manganate (LSM) compositions, with catalytic activity further enhanced by doping with cobalt.
4. Cathodes with various ratios of Lanthanum to Strontium were constructed and tested. Also, cathodes incorporating cobalt oxide were tested.
5. Cathode studies are particularly useful in optimizing fuel cell electrodes. The project used current versus over potential (Tafel) plots, and impedance spectra.
6. The investigator found that doping the cathode with cobalt could reduce cathode impedance at 600^{o}C, and increase the maximum power density by more than a factor of two; however, the goal of a 1 Ohm-cm^{2} composite membrane resistance was not achieved at 600^{o}C.

Conclusions:

1. The composite cathode structure developed is relatively easy to fabricate.
2. The membrane is best anode-supported rather than cathode-supported.
3. The composite cathode structure consisted of a catalytic layer of LSM 85 / YSZ and a current collecting layer of LSM 45.
4. The best composite cathode structure consisted of a catalytic layer of LSM 85 / YSZ and a current collecting layer of LSM 45. Doping with Cobalt (not Cobalt Oxide) content was shown to improve performance at low temperatures.
5. Complete analysis of the kinetic data obtained from these experiments proved to be beyond the scope of this project. However, clear trends in performance, such as improvements due to Cobalt doping, were readily apparent.

Benefits to California:

Results of this research were presented at the San Francisco Local Section meeting of the Electrochemical Society. The research will also serve as a starting point for further research on cathode microstructure and kinetics at low temperatures.

When the cathodes formulated as a result of this work are incorporated into commercial fuel cell structures, greater efficiency could be obtained at reduced temperatures. This can accelerate the adoption of solid oxide fuel cells for applications such as distributed power generation. This in turn would lead to reduced strain on the aging electricity transmission grid, greater reliability, and substantive cost savings due to greater efficiency.

Recommendations:

The composite cathode architectures and materials identified in this project offer improved performance at lower temperatures. In particular, LSM 85 / YSZ catalytic layers exhibited the best performance at low temperatures. It is recommended that an anode-supported solid oxide fuel cell membrane configuration be adopted, with thinner composite cathodes than originally envisioned, and that the composite cathode be applied by the colloidal methods described in this work.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Corrosion Resistant Coating for Carbonate Fuel Cell Components

EISG Grant Number: 00-05
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Yuhong Huang (818) 727-9786
Organization: Chemat Technology, Inc.
Grant Amount: $75,000
Status: Completed

Project Description:
Molten carbonate fuel cells are energy-efficient and environmentally clean devices for the generation of electric power. They can be fueled directly with natural gas or biomass-derived gasses. High capital cost and durability problems have slowed deployment of these fuel cells. The durability problems derive primarily from corrosion of system components by the carbonate. Although molten carbonate fuel cells (MCFC) are now being offered in sizes from 0.3 megawatts (MW) to 3.0 MW, warranties are limited, and service contracts are expensive (~$200/kW per year).

Molten carbonate fuel cells offer higher potential energy efficiency (~60%) than phosphoric acid fuel cells (~45%), micro-turbines (~28%), mid-sized gas turbines (~38%), or natural-gas-fueled reciprocating engines (~38 %). A molten carbonate fuel cell would be an excellent candidate for grid-connected distributed generation if its cost and durability problems were resolved. In a distributed-generation scenario the molten carbonate fuel cell could cleanly, quietly, and efficiently provide electricity. Molten carbonate fuel cells could be sited in dense urban areas without a negative effect on air quality.

In a recent (2003) survey conducted by the California Power Authority, molten carbonate fuel cells provided the lowest cost electricity ($0.13/kilowatt hour (kWh) before incentives) of any fuel cell available for installation. Maintenance was included in the cost estimates.

In this project the researcher proposed applying a sol-gel coating to reduce the corrosion of the cathode current collector (CCC) and the cathode material. Experts consider corrosion in these areas the most important factor impairing the useful life of carbonate fuel cells. The researcher proposed depositing a lithium-cobalt dioxide ($LiCoO_2$) coating on a porous nickel cathode substrate and a corrugated CCC and testing the performance of these components with the new coating. The researcher chose $LiCoO_2$ for the coating material because it has high electronic conductivity and high corrosion resistance.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using a sol-gel coating ($LiCoO_2$) to reduce the corrosion of cathode current collector and nickel oxide (NiO) cathode in molten carbonate fuel cells. The researcher established the following project objectives:

1. Improve the corrosion resistance of the NiO cathode and cathode current collector.
2. Increase the lifetime of molten carbonate fuel cells by 100%.
3. Determine economic feasibility of the coating.
4. Determine technical feasibility by evaluation of $LiCoO_2$ film in the fuel cell operating environment.

Actual Outcomes:

1. Data collected in this project indicated a decay rate of about 10 millivolts (mV)/1000 hours. This rate was approximately the same for coated and uncoated samples.

Electrolyte creepage loss was one-third less on the coated CCC than on the non-coated control sample. Electrical resistance of the coated CCC was stable for an 1800-hour test.

2. The researcher claimed MCFC life could be extended by a factor of two to five but did not include a product-life-cycle analysis in the final report to support that claim. Some data in the final report indicate that fuel-cell life could be extended with the $LiCoO_2$ sol-gel coating. On the other hand, one test apparently failed at 3700 hours. No explanation was given for the early termination of that test.
3. The researcher did not provide economic feasibility information. He stated this sol-gel process is inexpensive (<$1per square meter).
4. The researcher developed coating methods for both the porous nickel and corrugated CCC. The coatings were successfully applied.

Conclusions:

1. Data presented in the final report support the claim of reduced corrosion of the CCC when coated with $LiCoO_2$.
2. No product-life-cycle analysis was included in the final report. The performance charts in that report indicate fuel-cell failure in as little as 3700 hours. Scientific literature contains data for single-cell, fuel-cell tests surpassing 15,000 hours with decay rates of less than 5mV/1000 hours. The researcher may not have adequately characterized the life-extension benefits of the $LiCoO_2$ coating.
3. The Program Administrator cannot determine the economic feasibility of the coating process without knowing the life extension of the MCFC and the coating cost relative to the costs of other components.
4. The researcher was able to apply the sol-gel coating to the critical MCFC components. The coating did not degrade the performance of the components.
5. The researcher should be encouraged to continue this line of work. It appears that substantial progress has been made toward reducing corrosion in the molten carbonate fuel cell. Unfortunately the researcher did not present project data in the final report in a manner that clearly proves the feasibility of this project.

Benefits to California:

Molten carbonate fuel cells offer the potential of high fuel efficiency and extremely low exhaust emissions. These properties are highly desirable for grid-connected distributed-power systems. Successful introduction of a durable MCFC at a reasonable capital cost could speed the introduction of distributed generators into the power grid. Overall fuel efficiency would be greatly improved for generation of electricity in California, and air emissions would be greatly reduced. Insufficient data were presented to quantify the benefits.

Recommendations:

The researcher has made significant progress in addressing the durability of MCFCs. Unfortunately the data presented in the final report (Appendix A) is not in a form that allows one to determine the magnitude of the advance. The Program Administrator recommends the following:

1. Clearly address the project objectives in a technical report. Explain the rapid decline in performance and the early cell failure shown in Figure10a of Appendix A.
2. Quantify the results and compare to existing life and durability data for near-commercial MCFCs.
3. Work with a major developer of MCFCs such as FuelCell Energy to determine the value of the coating in a real-world product.
4. Obtain patent protection for the process used to coat the MCFC components.

5. Analyze material safety data for the $LiCoO_2$ to ensure compliance with existing regulations.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Cost Effective Lost Distortion Adjustable Speed Drive

EISG Grant Number: 99-34
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Arthur Iverson (408) 354-7972
Organization: Spinel LLC
Grant Amount: $75,000
Status: Cancelled

Project Description:
The purpose of this project is to research the feasibility of a new low-cost pulse width modulated (PWM) inverter design capable of producing pure waveforms for controlling adjustable speed drive (ASD) motors. The focus of the project is to establish the feasibility of building ASDs that do not produce the distorted waveforms that cause premature motor failures such as those generated by the ASDs now in use. Electric motors are designed to run on sinusoidal utility power (60 Hz). An advanced ASD, employing high frequency switching >60kHz, allows the synthesis of essentially pure sine waves that are cleaner than those received from the Utility and provides normal motor life. Agricultural uses of ASD motors include programmed pump irrigation, and uses in produce conveyers and processing systems. ASD pumps are also used to control water flow in water transport and sewage treatment plants.

Proposed Outcomes:
- Fabricate and test a prototype motor controller on a three-phase 5 HP motor.
- Develop a prototype three-phase inverter capable of producing pure variable frequency sine waves with current harmonics less than 5% and efficiency greater than 92% regardless of cable length.
- Produce a feasibility assessment based on prototype performance testing.

Anticipated Benefits:
- Low cost solution to eliminating premature ASD motor failures due to leading edge PWM pulse spikes that cause premature insulation failure.
- Eliminate or minimize costly harmonic filters and associated engineering analysis that is currently required for harmonic sensitive ASD installations.
- Significantly increase ASD market penetration which is currently only 9% due to lack of confidence in the technology.

Project Status:
The project was cancelled due to failure on the part of the contractor to show evidence of reasonable progress during the term of the grant agreement.

Development of a PEM Electrolyzer: Enabling Seasonal Storage of Renewable Energy

EISG Grant Number: 00-25
PIER Area: Renewables
Principal Investigator: Peter Lehman (707) 826-4345
Organization: Humboldt State University Foundation, Schatz Energy Research Center
Grant Amount: $74,478
Status: Completed

Project Description:
Many renewable energy sources are intermittent. Because of this characteristic, it is difficult to sell the electricity generated by those renewable sources into a forward market. The result is less revenue to the owner of the generator. One solution is to generate hydrogen with the renewable energy, store it, and consume the hydrogen in a fuel cell to provide electricity when needed. While holding hydrogen gas at high-pressure is the lowest cost method of hydrogen storage, it is not inexpensive. Compressing hydrogen is a major cost and thus is a deterrent to converting electricity generated from renewable sources to hydrogen to be stored for future use. Current technology hydrogen generators produce hydrogen at up to 375 psig (pounds-force per square inch gauge). Mechanical compression of the hydrogen, a highly energy intensive process, is used to achieve storage pressures. In addition, most current generation high-pressure electrolyzers incorporate caustic liquid alkaline electrolytes and other hazardous materials. To solve the compression cost problem, one needs a non-caustic electrolyzer that produces hydrogen at storage pressure, eliminating the need for mechanical compression. An electrolyzer of this type is not currently available.

If the hydrogen storage cost problem were solved, renewable energy generators could provide more predictable power, allowing Californians to rely on more renewable energy. Generators would be able to utilize the forward markets and realize higher net revenues. With economical storage investors could develop more wind and solar electricity generators throughout the State. By adding predictable renewable energy into the California grid, grid operators might have less need to dispatch energy-inefficient “peaker” generators. In addition, if renewable generator output were more predictable, grid operators would not need to maintain fossil fueled plants at ready for system backup.

The researcher in this project proposed to produce high-pressure (2000 psig) hydrogen with a proton exchange membrane (PEM) electrolyzer. PEM electrolysis uses a solid electrolyte identical to that used in PEM fuel cells. PEM solid electrolyte is free of toxics and cannot spill or leak. In comparison with the more established alkaline electrolyzer technology, PEM electrolyzers are safer by virtue of their solid, inert electrolyte. They are capable of being operated at much higher pressures, and they can sustain high current densities. Other researchers have developed the concept of a PEM electrolyzer. Several PEM electrolyzers are available in the market today.

The advancement of science in this project was to design the electrolyzer to withstand high pressures. The researcher in this project developed a design and selected appropriate materials to produce hydrogen at pressures of 2000 psig. The design had to solve the problem of hydrogen cross-over (to the anode) as the pressure increased. Safe handling of the oxygen developed in the electrolyzer was another key design challenge.

Proposed Outcomes:
The goal of this project was to determine the feasibility of designing a proton exchange membrane (PEM) electrolyzer to produce at least three standard liters per minute (slm) of hydrogen at 2000 pounds per square inch gauge pressure (psig). The researchers established the following project objectives:

1. Develop a PEM electrolyzer to generate three standard liters per minute of hydrogen.
2. Develop a PEM electrolyzer to generate hydrogen at 2000 psig without the use of mechanical pumps.
3. Achieve voltage efficiency of the electrolyzer > 90%.

Actual Outcomes:

1. The one-cell electrolyzer developed in this project produced 0.22 slm of hydrogen per minute. To achieve the desired 3 slm of hydrogen per minute the researcher proposed building a stack of 14 cells.
2. The researcher achieved the 2000 psig pressure objective in one-cell and two-cell electrolyzers.
3. The researcher measured the voltage efficiency at 92% and 95% in two different tests.

Conclusions:

1. While showing a path to achieve the objective of 3 slm, the researcher should evaluate the costs associated with combining multiple cells to achieve the desired hydrogen output.
2. The researcher achieved a major pressure objective. This is a notable achievement and should reduce the cost of storing hydrogen produced by renewable energy generators or regenerative fuel cells.
3. The researcher met the voltage efficiency goal. Electrolyzers with higher voltage efficiency numbers are more energy efficient.
4. The researcher considers the specific materials used to prove feasibility confidential. The researcher also considers his solution to the hydrogen cross-over problem confidential.

Benefits to California:
If the technology developed in this project were to be deployed commercially, Californians could enjoy the benefits of more renewable energy in the supply mix. A major benefit would be reduced air emissions because grid operators would not dispatch fossil fuel burning power plants for energy nor have them run as backup to support the grid if a renewable energy generator were suddenly to reduce output. Emissions from the standby generators reduce the air quality benefits of renewable energy generators. A second advantage would be greater grid stability due to the distributed nature of the renewable generators and the capability to produce electricity from the stored hydrogen when needed.

Recommendations:

1. The researcher should calculate the "round trip" efficiency of converting renewable electricity to stored hydrogen and back to electricity. The U.S. DOE has established a goal of 70% for round trip efficiency. To achieve 70% one would need a hydrogen fuel cell operating near 80% efficiency and an electrolyzer operating at nearly 90% efficiency.
2. The researcher should calculate the expected cost of the PEM electrolyzer. The researcher should express cost in dollars per megawatt hour ($/MWh). Research to reduce electrolyzer cost will be needed before a commercial product can be produced. The researcher should identify less costly but suitable diffuser materials for use in the module.
3. Efforts should continue to increase the working pressure of the electrolyzer.

4. Long-term bench tests should be conducted to determine the durability and reliability of the module design.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Development of Optimum Design Configuration and Performance for Vertical Axis Wind Turbine

EISG Grant Number: 00-17
PIER Area: Renewables
Principal Investigator: Hamid R. Rahai (562) 985-5132
Organization: California State University, Long Beach (CSULB) Foundation
Grant Amount: $69,781
Status: Completed

Project Description:
This project was undertaken to improve the efficiency of vertical axis wind turbines with the expectation that the inherently simple vertical axis turbines could be manufactured at low cost, leading to their widespread use. The research proposal noted that small units could be manufactured for distributed generation of electricity in residential and commercial locations. The units would be grid connected to take advantage of net metering and would provide pollution free generation of electricity using a renewable resource at a cost competitive with power supplied by the grid.

The researcher estimates that a moderate sized residential unit would generate 2700 kilowatt hours (kWh) per year and that the low cost of the unit would allow a simple payback of investment from energy savings in three years. If 100,000 of these small wind turbines were installed in California they would eliminate the annual generation and release of nearly 10 tons of oxides of nitrogen and over 13 tons of carbon monoxide gas. These calculations are based on California's 2007 air emission standards for natural gas burning distributed generation. Displacing older generators would result in greater environmental benefits.

The simplest vertical axis wind turbine is called the Savonius wind turbine. Operation of the Savonius wind turbine is based on the difference of the drag of its semi-spherical vanes, depending on whether the wind is striking the convex or the concave part of the vane. The advantage of this type of wind turbine is that it is self-starting and relatively independent of the wind direction. It is simple to design and has relatively low construction cost. However it has low efficiency.

The approach taken by this project was to improve the efficiency of the vertical axis (Savonius-type) wind turbine by modifying the blades. The blade shape was iteratively designed using Computational Fluid Dynamics software embedded within a torque maximization program using the Trans Finite Interpolation method. A scale model vertical axis wind turbine featuring the optimized blade design was constructed and tested in the Boeing/CSULB low-speed wind tunnel. Wind tunnel tests confirmed a 40% increase in peak power coefficients over prior art.

Proposed Outcomes:
The goal of this project was to determine the feasibility of developing a high efficiency Savonius-type vertical axis wind turbine by modifying the blade (airfoil) shape. The researcher established the following project objectives:

1. Increase the efficiency of the vertical axis wind turbine design 20% to 30% by applying computational fluid dynamics (CFD) software to optimize the airfoil shape.
2. Experimentally verify the design by testing scale model wind turbines in the Boeing/CSULB low speed wind tunnel.

Actual Outcomes:

1. The researcher used CFD software and an optimizer routine for the shape-optimization process. Results of this study showed nearly 27% improvement in the torque coefficient for both single and two-blade configurations with the optimized geometry. The computations also led the researcher to investigate the placement of slots in the airfoils at the location where maximum flow separation was observed at high angles of attack. The improvement in the torque coefficient without the slots was greater than that with the slots.
2. The researcher fabricated two small-scale vertical axis wind turbines, one with and one without span-wise slots. They were tested in the Boeing/CSULB low speed wind tunnel at three free-stream mean velocities: 6.8, 8.0, and 9.75 m/sec (15.2, 17.9, and 21.8 miles/hr). The experiments were performed for both zero and 48% overlap of the blades. Torque was measured directly using an electric dynamometer. Results showed nearly 40% and 17% improvement in power coefficient for the optimized blades without and with the slots respectively. The conditions for these results were zero overlap at the mean velocity of 6.8 m/sec.
3. It was determined the optimized wind turbine operated more efficiently than the Savonius wind turbine at all tip speed ratios. A significant result of this study was the determination that the optimized wind turbine operated efficiently at a much higher rotation rate than the Savonius wind turbine could operate. The Savonius wind turbine provides its maximum power coefficient (about 30%) at a tip speed ratio of approximately 1.0. The optimized wind turbine with no slots and zero overlap produced a power coefficient greater than 40% at a tip speed ratio of 1.6. At this tip speed ratio, the Savonius turbine power coefficient dropped to below 5%.

Conclusions:

1. This project confirmed the feasibility of using computational fluid dynamics software to aid the design of single blade, vertical axis, wind turbine airfoils. It is reasonable to expect investigations of multi-bladed vertical axis wind turbines could be accomplished using the same computational approach. CFD software is already used in other energy products including centrifugal pumps vanes and gas turbine compressor and turbine blades.
2. Wind tunnel testing confirmed the most efficient vertical axis wind turbine design used the optimized airfoils without slots and mounted with no overlap. This design demonstrates high efficiency over the range of wind speeds from 6.8 m/s to 9.75 m/s.
3. The optimized wind turbine provided higher power coefficients over a broad operating range. The characteristic of providing power at much higher tip speed ratios potentially increases the total power produced by the turbine. The optimized wind turbine provided optimum power at a tip speed ratio of 1.6. This is 60% faster than the Savonius wind turbine. For this reason the redesigned turbine provides 60% more power than a Savonius turbine operating at a tip speed ratio of 1.0. Coupled with the approximate 33% increase in the power coefficient, the new design could produce over twice the power of the conventional Savonius wind turbine under comparable conditions.

Benefits to California:

Because the researcher saw a market in small vertical-axis wind turbines he did not make absolute comparisons between the optimized vertical axis wind turbine and the conventional horizontal axis wind turbines that are commercially available. The researcher speculated that a one-kilowatt vertical-axis wind turbine generator system could be built for $300. To ascertain the value of this research to the California ratepayer, the Program Administrator requires a more accurate estimate of the cost to construct and maintain a vertical axis wind turbine with optimized

blades. This estimate could assume deployment in one of California's traditional wind regions or in high-density urban areas. The improved design vertical axis wind turbine could prove to be more cost effective than horizontal axis turbines because of the improvements in blade design and the elimination of equipment required to maintain a horizontal axis machine heading into the wind. Any improvements to the cost and durability of wind turbine generation systems could have significant favorable impacts on the California ratepayer. These benefits include: lower cost renewable resource electricity; increased production of renewable resource electricity, reduced air pollution; and increased energy security through local electricity production.

Recommendations:
This project demonstrated the utility of using CFD to redesign the blades of vertical axis wind turbines. The redesigned wind turbine can generate electric power at relatively moderate wind speed with an efficiency that is near that of a comparable horizontal axis wind turbine. The Program Administrator recommends that a thorough cost analysis be completed for the redesigned vertical axis turbine. That study should focus on production costs to build and install it in selected markets. A person familiar with maintaining wind turbines in a California wind region should then evaluate maintenance costs for the vertical axis machine. If these studies indicate a significant life cycle cost advantage, the researcher should team with a wind generation company to field-test a CFD-improved vertical axis wind turbine at a power level of 1 kilowatt or more at wind speeds of 10-15 miles/hr. The Program Administrator recommends significant instrumentation be applied to that demonstration turbine to ascertain it performance, sensitivity to environmental contamination, and noise levels.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Energy-Efficient Process for Using Membrane Technology to Treat and Recycle Agricultural Drainage Water

EISG Grant Number: 01-23
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Ronald Enzweiler (925) 283-4918
Organization: WaterTech Partners
Grant Amount: $74,788
Status: Completed

Project Description:
U.S. Environmental Protection Agency has identified agricultural drainage/runoff as a significant contributor to surface water pollution. Pollutants that result from drainage/runoff are sediment, nutrients, pathogens, pesticides, and salts. The sources of these pollutants are confined animal facilities, grazing animals, and agricultural activities: plowing, pesticide spraying, irrigation, fertilizing, planting, and harvesting. In California, the viability of farming on 861,423 acres of prime farmland in western San Joaquin Valley is threatened by unresolved drainage problems. Drainage cleanup and reuse (recycling) are not being considered as a solution because a viable technology does not exist to recover 99% water content of agricultural drainage in a reliable, energy efficient, and cost-effective manner. Membrane technology has potential as a recycling solution for the agricultural drainage problem. It is extensively used for seawater desalination, but fouling problems have limited its ability to treat agricultural drainage. Although seawater total dissolve solids (TDS) are 35,000 milligrams per liter (mg/L) versus 3,000 to 12,000 mg/L TDS for agricultural drainage, high calcium sulfate ($CaSO_4$) saturation in drainage has limited recovery by reverse osmosis to < 50%.

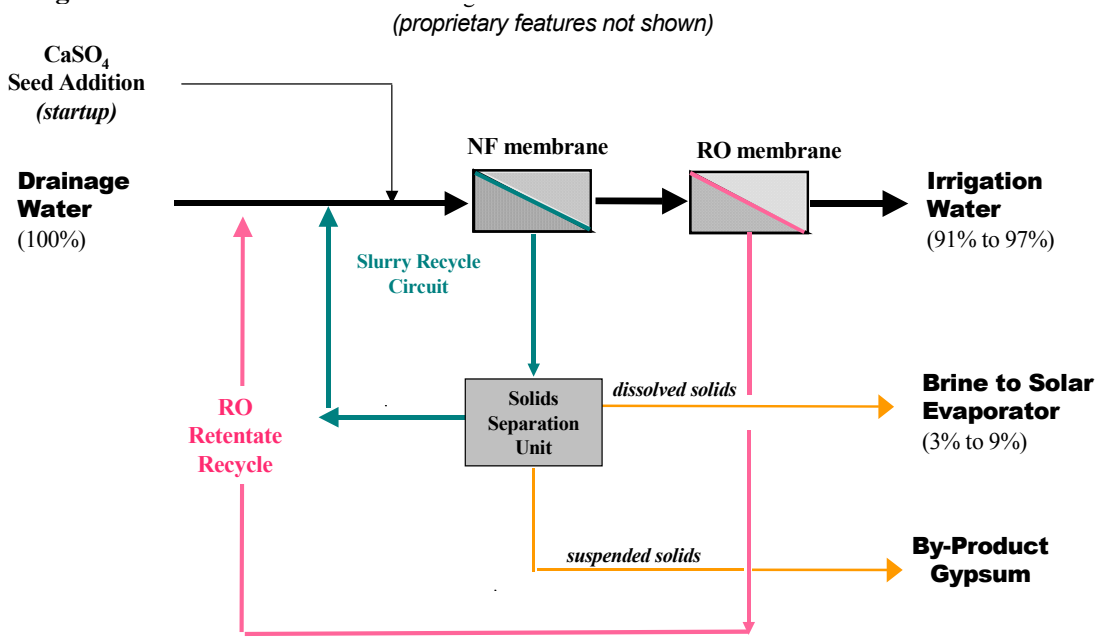
The estimated public funds required to implement the U.S. Bureau of Reclamation disposal plan is $716 million, projected to be $425/acre-foot (AF). The utilization of an improved membrane technology to recycle 80,000 AF of agricultural drainage for irrigation would avoid significant public fund expenditures and reduce processing energy consumption from 3,200 kilowatt hours per acre-foot (kWh/AF) (based on best seawater desalination) to 2,400 kWh/AF.

WaterTech Partners proposed to improve the reverse osmosis recovery and reduce energy consumption by developing a two-pass membrane process utilizing preferential precipitation of dissolved $CaSO_4$ (see Figure below). In this arrangement, the precipitated $CaSO_4$ (as well as other salts) would be removed from the drainwater feed in the 1st pass nanofiltration (NF) membrane. The 2nd pass reverse osmosis unit would continue the clean-up of the water to meet irrigation requirements (<500 mg/L TDS with a sodium adsorption ratio <4.0).

Proposed Outcomes:
The goal of this project was to demonstrate the feasibility of the proposed two-pass membrane system as a viable technology solution for agricultural drainage water recycling. The researchers established the following project objectives:

1. Prove that "preferred precipitation" nanofiltration will lower agricultural drainage hardness from 2,000 mg/L to less than 50 mg/L.
2. Demonstrate the pilot-scale operation of a two-stage membrane filtration in which the total energy consumption is less than 2,400 kWh/AF (25% less than most efficient commercial reverse osmosis desalination processes).
3. Demonstrate the pilot-scale operation of a two-stage membrane filtration whose total cost is 25% below the least costly commercially available seawater desalination process.

Block Diagram of the Basic Process:



Actual Outcomes:

1. The researchers identified, through performance testing, a preferred nanofiltration membrane. They tested the nanofilter with "preferred precipitation" and were able to operate, on agricultural drainage, with less fouling than without "preferred precipitation."
2. The simulated specific energy consumption for a two-stage membrane system using "preferred precipitation" was lower (2,163 kWh/AF) than 2,400 kWh/AF (as proposed) for only one case: feed that is solar pre-heated (95°F) and with a TDS levels of 6,450 mg/L. The researchers calculated the membrane energy consumption from feed pressure and flow for the simulated two-stage system.
3. The estimated costs for a water plant using the technology developed in this project are $564/AF to $845/AF depending on feed TDS and use of solar energy for feed preheating. For comparison, the TDS of seawater is 35,000 mg/L and its desalination costs about $850/AF. However, a direct comparison with seawater desalination would be misleading because of the $CaSO_4$ precipitate problem associated with agricultural drainage water.

Conclusions:

The researchers successfully proved the feasibility of "preferred precipitation" combined with nanofiltration as a method to process agricultural drainage water without fouling.

1. The use of "preferred precipitation" provides a method to process and recycle agricultural drainage using membrane technology without fouling problems. This was proved feasible by processing 1,500 gallons of Panoche tile-drain water over a 150 hour test period.
2. The amount of electric power for a simulated two-stage membrane water treatment plant did not meet the proposed goals of the project (<2,400 kWh/AF), but it is less than state-of-the-art seawater desalination reverse osmosis plants.
3. The water production cost of the two-stage membrane water treatment plant is less than a typical seawater desalination reverse osmosis plant, but it is difficult to conclude that this

is a level field comparison. Note that seawater desalination reverse osmosis plants process feedwater with higher inlet TDS than the water from agricultural drainage.

Benefits to California:
The project demonstrated that "preferred precipitation" combined with nanofiltration is a legitimate method for processing agricultural drainage. The research has significant value for the processing of agricultural drainage and recycling irrigation water. It is an environmentally attractive method of drainage processing compared to the proposed evaporation ponds.
It is unclear if this technology saves electric energy. The researchers derived an estimate of electric consumption by calculation based on feed pressure and flow, instead of measuring it. Since feed pressure and flow vary over time, this calculation can be complicated when considering real-world pump-motor systems.

The researchers also cite that this system could save 418 million kWh/yr, but they compared this system to a seawater desalination plant. Not all of the irrigation water used is from seawater desalination plants. They did not include the pumping energy to deliver irrigation water or the potential to use this in power plants to reduce imported water.

The researchers identified optimization methods that may be explored to further reduce energy consumption and energy cost of the two-stage water treatment plant. These may include off-peak operation, use of solar pre-heating of feedwater, and use of single-stage membrane systems.

Recommendations:
The Program Administrator makes the following recommendations for this project:

1. Future development and testing should include energy optimized pilot system operation where energy consumption and clean water production are measured.
2. The researcher should compare energy and cost of this technology with the primary drainage treatment method: evaporation ponds or other methods that treat brackish water, not seawater.
3. The researcher is encouraged to identify electric energy savings other than seawater desalination such as avoided irrigation water pumping.
4. The researcher should pursue ways to further reduce the energy consumption of the two-stage water treatment plant.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

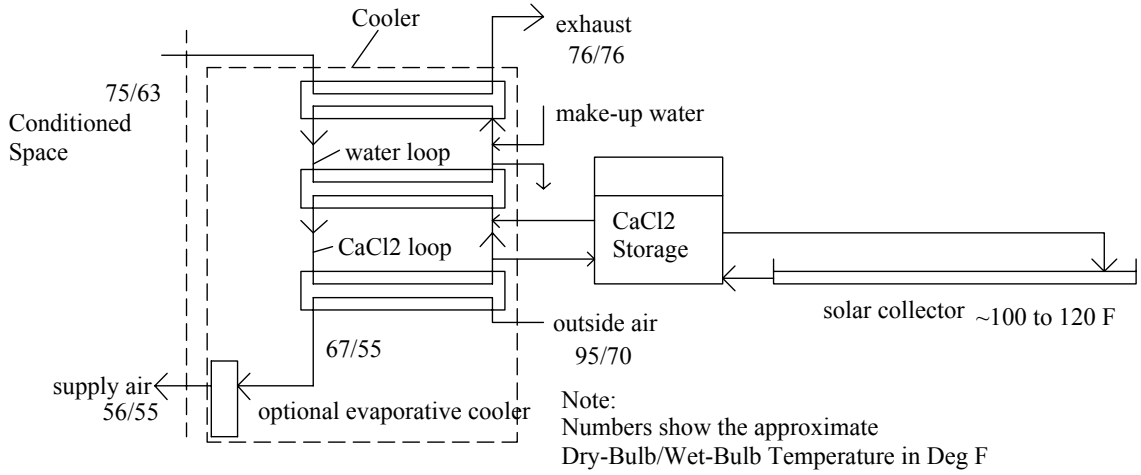
Evaluation of New Solar Air-Conditioning System

EISG Grant Number: 00-16
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Bill Kopko (703) 323-9578
Organization: WorkSmart Energy Enterprises, Inc.
Grant Amount: $74,546
Status: Completed

Project Description:
Air conditioning powered by solar energy has great potential, in part because high demand for cooling usually coincides with plentiful sunlight. The intensity of solar energy on the roof of a typical single-story building in California is roughly ten times the cooling requirement for the same building. Solar air conditioning at an economically competitive level could reduce electricity costs for residential and small commercial customers. This would cut the growth of peak electric demand and ease the increasing pressures on generating capacity, transmission, and distribution. Currently available technologies are neither practical nor cost-effective. Photovoltaic (PV) systems require a large roof area and cost many times more than a conventional air conditioner. Thermally driven absorption cooling requires costly, high-temperature collectors and undesirable cooling towers. Furthermore, these systems have a disconnect of several hours between peak cooling capacity and peak cooling demand. That in turn requires electric or thermal storage in order to maximize the solar contribution.

A solar air-conditioning system employing relatively inexpensive low-temperature collectors, coupled with an innovative desiccant dehumidification and evaporative process, provides a new prospect for cost-effective solar cooling. If proven practical and economical, the savings potential in the California market for rooftop air conditioning would be 8.5 billion kilowatt hours (kWh) in energy and $1 billion per year. This corresponds to a reduction in electric demand in California of 5,500 megawatts (MW). The potential nitrogen oxides (NO_x) reduction in California is 2,400 tons annually, based on the state average 2000 annual NO_x output emission rate of 0.564 pounds per megawatt hour (lb/MWh).

The research concept couples modest-cost, low-temperature collectors with a low-cost calcium chloride solution for desiccant dehumidification and thermal storage. The addition of an evaporative cooler produces air conditioning at a competitive cost. The economic viability of this concept depends on optimizing the system and its components and on developing two key innovations—a low-cost heat exchanger and a solar thermal desiccant-regeneration subsystem.



A calcium chloride solution concentrates (regenerates) while passing over the solar collector array. The concentrated calcium chloride solution cools via a plastic liquid-to-liquid heat exchanger and is then exposed to incoming outside air through a direct-contact enthalpy exchanger, similar to an evaporative cooler. Exhaust air from the conditioned space cools evaporatively, and the cooled water from the evaporative cooler sump reduces the temperature of the warm, concentrated calcium chloride solution through the plastic heat exchanger.

Proposed Outcomes:
The goal of this project was to determine the feasibility of a thermally driven, solar air-conditioning system employing desiccant dehumidification low-temperature collectors for desiccant regeneration and evaporative cooling. The researchers established the following project objectives:

1. Identify a design for a leak-free plastic liquid-to-liquid heat exchanger with a heat-transfer coefficient of 50 British thermal units per hour per square foot per degrees Fahrenheit (BTU/hr/ft^2/^{o}F).
2. Achieve collector water-evaporation rate of 1.0 pounds per day per square foot (lb/day/ft^2).
3. Plan for the first cost in the same range as high-efficiency electric air conditioning evaporator rooftop systems ($1,800 to $2,200 per ton installed).

Actual Outcomes:

1. Nine different designs of low-cost, liquid-to-liquid heat exchangers were evaluated; two were tested. The preferred configuration consisted of plastic sheets welded together to form two counter-flow channels. It was the easiest to assemble and achieved a heat-transfer coefficient of 40 BTU/hr/ft^2/^{o}F, but the development of small circuit-to-circuit leaks prevented lengthy and repeatable testing.
2. Sample solar-collector tests measured the evaporation rate from a calcium chloride solution. The sample collector consisted of a plastic plate filled with calcium chloride solution and covered with a black polyethylene film. The measured evaporation rates ranged between 0.5 and 1.0 lbm/day/ft^2 under partly cloudy summer conditions in Northern Virginia.
3. The estimated cost per ton was based on modeled subsystem sizes and projected costs for materials, factory labor, mark-up, freight, and installation. The total projected price to an end user was $1,825 per ton. Electricity requirements are expected to be on the order of 0.25 kilowatts per ton (kW/ton), about ¼ that of a high-efficiency electric rooftop package. Annual water usage is estimated at 6,000 gallons per ton for a typical California application.

Conclusions:

1. Low-temperature solar collectors can provide effective regeneration of a calcium chloride liquid desiccant solution. Average evaporation rates of 0.5 to 1.0 lbm/ft^2/day are achievable in California with simple open-collector designs.
2. A low-cost, high-performance, liquid-to-liquid heat exchanger was tested with an overall heat-transfer coefficient in the range of 40 BTU/hr/ft^2/^{o}F. Leak-proof construction and longevity are important areas for future attention.
3. A projected 75% reduction in electricity use for air conditioning corresponds to an electric Coefficient of Performance (COP) equivalent of 14. By contrast, a high-efficiency rooftop package has a COP of 3.5.
4. Water requirements appear to be modest and do not add appreciably to the operating expenses. At $3/1,000 gallons, the cost for water is $18/ton/yr, a fraction of the cost for an electric air conditioning evaporator unit. If the entire California inventory of rooftop

air conditioning switched to this approach, the annual water requirements would be 100,000 acre-feet. In contrast, California consumes 9.5 million acre-feet annually for urban uses.

5. Modeling, coupled with preliminary cost estimates for materials, labor, markups, and installation, indicates that the solar air-conditioning system has the potential to achieve installed costs of $2,000/ton, on par with the typical installed cost of efficient rooftop models.

The technical feasibility of a novel solar air conditioner incorporating low-cost materials has been proved. Simple heat and mass-transfer tests were performed with representative material samples. The measured properties were used to size and cost the system. Beyond the scope of this small grant, considerable work remains to scale up the subsystems; to test prototype systems for performance and durability in an outdoor environment; and to confirm cost estimates for manufacturing, distribution, and installation.

Benefits to California:

The primary benefit to the ratepayer from this research is increased affordability of electricity in California. The novel solar-air-conditioning concept would reduce the biggest cause of peak electricity demand. That would enable increased utilization of the generation, transmission, and distribution system and would delay new generating and transmission investments, lowering the cost of delivered electricity. Reducing peak demand also helps relieve congestion and improves the reliability of the power supply.

An economic solar air conditioner would also help California adopters of the technology control their energy expenses. The light commercial and small industrial sectors would best be able to utilize this technology. The electricity usage for rooftop air conditioning in California is 11.4 billion kWh per year. With energy savings of 75% projected, the displacement potential of solar air conditioning in these California sectors is estimated at 8.5 billion kWh annually. That corresponds to a demand reduction in the vicinity of 5.5 GW and a consumer cost savings of $1 billion per year.

Recommendations:

After taking into consideration (a) research findings in the grant project, (b) overall development status, and (c) relevance of the technology to California and the PIER program, the Program Administrator has determined that the proposed technology should be considered for follow-on funding within the PIER program.

Receiving follow-on funding ultimately depends upon (a) availability of funds, (b) submission of a proposal in response to an invitation or solicitation, and (c) successful evaluation of the proposal.

The solar air-conditioning concept is a novel approach that recognizes the importance of initial cost to economic viability and market acceptance. Although the scale-up of the concept, its durability, and its true cost remain uncertain, it merits funding for the next development step. Further work should address the following:

- Heat-exchanger design and fabrication techniques for low cost and high performance.
- Heat-exchanger material that is inexpensive yet durable for ten to fifteen years of operation.
- Collector subsystem design that meets the $70/ton material cost target yet is rugged enough to endure ten years of outdoor operation.
- Bench-scale system test to verify cooling capacity and parasitic electricity requirements.

- Following additional research and laboratory prototype testing, verification of the $2,000-per-ton installed target requires in-depth analysis of material, manufacturing, distribution, sales, and installation costs.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Flat-Plate Micro-Dish Photovoltaic Concentrator Module

EISG Grant Number: 03-18
PIER Area: Renewable Energy Technologies
Principal Investigator: Akira Terao (408) 991-0915
Organization: SunPower Corporation
Grant Amount: $74,985
Status: Cancelled

Project Description:
The purpose of this project is to determine the feasibility of using an array of low-profile small-size dish reflectors to concentrate sunlight onto photovoltaic cells.

Proposed Outcome:
- A concentrator prototype will be fabricated and tested.

Anticipated Benefit:
- The proposed technology could produce a low-profile concentrator system for under $2/watt that could be used in the same tracking systems used for flat-plate tracking systems.

Project Status:
The award was declined so the project was cancelled.

Improvement of Rechargeable Li-ion Batteries Performance by Surface Modification of the Cathode

EISG Grant Number: 01-21
PIER Area: Renewables
Principal Investigator: Pieter Stroeve (530) 752-8778
Organization: University of California, Davis
Grant Amount: $75,000
Status: Completed

Project Description:
Rechargeable batteries are widely used as energy storage systems for renewable-energy technologies and power-quality systems. A battery system can give renewable-energy technologies around-the-clock viability by storing the electrical energy they produce for its most economical, strategic, and efficient uses. Batteries that combine high energy density with low cost and that are environmentally friendly would benefit the California renewable-energy market. Lithium-ion ($LiCoO_2$) battery technology offers higher energy density than most other commercial types, but at a generally higher cost per cycle. Lithium cobaltate batteries have been in commercial use since 1991. A new lithium-ion battery with different cathode chemistry (lithium manganate, $LiMn_2O_4$) has been identified as a possible replacement. It contains manganese (spinel) instead of cobalt and would be inherently safer and cheaper to produce. However, the spinel cathode has problems with capacity fading during cycling and with storage at elevated temperatures (55°–66° C). Specifically, capacity fading occurs during cycling because the crystal geometry weakens, especially in the cathode-surface region. At elevated temperatures, dissolution of the $LiMn_2O_4$ into the electrolyte enhances this process and leads to irreversible battery deterioration.

Resolution of issues relating to capacity fading would permit the manufacture of a high-performance battery at lower cost. The raw-material price of manganese oxide is $2.29/kilogram (kg), while cobalt oxide runs $39.60 to $41.80/kg. Lithium cobaltate batteries also incur the extra cost of a thermal protection circuit necessary to ensure safety during operation. Spinel is inherently safer, more environmentally benign, and less toxic than lithium cobaltate.

The principal investigator predicted that the use of surface-modified $LiMn_2O_4$ (SM-LMO) as the cathode material would alleviate or resolve the problems of capacity fading during cycling and after storage at elevated temperatures (55°–66° C). The researcher proposed to minimize surface degradation by surface modification on the molecular level. Specifically, the project used polymer-coated particles of $LiMn_2O_4$ to fabricate an experimental cathode. The principal investigator hypothesized that the polymer coating would inhibit Manganese (Mn+) dissolution at the surface and improve thermal stability at elevated temperatures, thereby extending battery life.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using surface-modified $LiMn_2O_4$ (SM-LMO) as the cathode material to reduce capacity fading in a rechargeable lithium-ion battery by inhibiting Mn^+ dissolution at the surface and improving thermal stability at elevated temperatures (55°–66° C). The researcher established the following project objectives:

1. Finalize the methodology for two surface treatments of the cathodes.
2. Determine the surface chemistry for each cathode.
3. Demonstrate that Mn^+ dissolution can be reduced by 30% to 50% in the cathodes.
4. Demonstrate that capacity fading can be reduced by 30% to 50% in the cathodes.

5. Show from the research findings that a successful surface treatment can reduce the manufacturing cost of lithium-ion batteries by 10% to 20%.
6. Investigate the effect of surface modifications on the reactions at the cathode/electrolyte interface and on the mechanism of capacity fading.

Actual Outcomes:

1. Two methods of cathode coating were implemented: one way consisted in applying poly diallyldimethylammonium chloride (PDDA) on the $LiMn_2O_4$ pellet; the other way consisted in applying a thin, molecular film on the $LiMn_2O_4$ powder before cathode fabrication. The investigation was limited to a PDDA solution-concentration range of 10 to 100 millimolar (mM) because the measured storage capacity for larger concentrations is lower than the untreated cathode. PDDA solution concentrations of 10, 20, 30, 50, and 100 mM were applied to the cathode pellet (weighing 8 mg) and powder (weighing 0.2 mg). For each of the PDDA concentrations investigated, more PDDA absorbed to the powder than the pellet.
2. Transmission electron microscopy (TEM) confirmed the existence of the polymer coating on the cathode surface. Scanning electron microscopy (SEM) showed that more PDDA absorbed on small $LiMn_2O_4$ particles than larger ones because the smaller ones have a larger relative surface area. Results indicate that capacity does not depend strongly on the thickness of the polymer layer.
3. The researcher did not quantify the reduction in Mn^+ dissolution.
4. Capacity stabilities of the PDDA-coated pellet and powder are 4.3±1.1% and 9.3±5.3%, respectively, after 5-10 charge/discharge cycles at room temperature. On average, the charge/discharge curves of the untreated PDDA-coated cathode after storage at 70° C for one week showed 18% to 20% loss of initial capacity. Diminished capacity after storage was about 12% and 6% for the PDDA-coated pellet and powder, respectively.
5. The findings do not specifically demonstrate that surface modification can reduce the manufacturing cost of lithium ion batteries 10%-20%. However, the researcher did note the wide difference in price of raw materials—manganese oxide ($2.29/kg) versus cobalt oxide ($39.60/kg to $41.80/kg). Additionally, PDDA can be used as a binder to reduce the amount of Teflon used in fabricating the cathode. That may further reduce cathode-manufacturing costs.
6. Cathode surface reactions were observed using *in situ* electrochemical atomic force microscopy (EC-AFM) at room and elevated temperatures. The measured capacity fading after storage decreased for coated cathode pellet and $LiMn_2O_4$ powder. Capacity fading measured on cathodes made of PDDA-coated $LiMn_2O_4$ was very small for cathodes obtained from powder coated in solution containing 30 and 50 mM PDDA.

Conclusions:

The researcher in this project provided a new approach to extending lithium-ion battery life. The data, while promising, are not sufficient to prove the feasibility of the concept.

1. Coating with a polymer film successfully modified $LiMn_2O_4$ nanoparticles used as active material in cathode fabrication. The coating method is sensitive to the initial powder dispersion and mixing procedure.
2. TEM, SEM and Energy Dispersive X-ray Analysis (EDAX) confirmed the formation of a thin polymer film on the surface of the $LiMn_2O_4$ nanoparticles. The Technical Reviewer indicated that the proposed model may be wrong because the results should have shown a strong relationship between cathode capacity and the thickness of the polymer layer.
3. The researcher did not specifically quantify the 30% to 50% reduction in LMO cathode Mn^+ dissolution; however, the researcher hypothesizes that the polymer coating protects

the $LiMn_2O_4$ particle surface from the full contact with the electrolyte and possibly blocks surface reactions that are responsible for capacity fading.

4. The researcher did not meet his initial goal of reducing capacity fading by 30% to 50% in LMO cathodes. However, there was measurable improvement in capacity fading—approximately 6% to 14% with the SM-LMO cathode after storage at room temperature. The researcher hypothesized that the higher capacity loss for the coated powder might be the difference in its mixing properties. It would have been beneficial if measured charge/discharge cycling results (5-10 cycles) for the untreated cathode had been included in the report. Without this data it is hard to draw a comparison with the measured results for the treated cathode.
5. The researcher's claim of reduced manufacturing costs was based solely on the lower raw-material price for manganese oxide compared to cobalt oxide. The true manufacturing costs are difficult to substantiate at this point in the development process.
6. The *in situ* AFM observation of the cathodes at room temperature shows changes in surface topography that follow potential cycling. These are attributed to the lithiation/delithiation processes that accompany the change in potential during charge-discharge cycling. These changes are related to either Mn^+ dissolution or film formation on the cathode surface. The researcher hypothesizes that the possible degradation mechanism is the reversible dissociation of the electrolyte salt lithium hexafluorophosphate ($LiPF_6$) to lithium fluoride (LiF) and phosphorus fluoride (PF_5). The PF_5 can, in turn, react with the manganese oxides on the surface to form manganese difluoride on the cathode and soluble products in the electrolyte. The soluble products in electrolyte could be phosphoryl trifluoride (POF_3) and difluorophosphate (PO_2F_2).

Benefits to California:
The employment of a lower-cost high-performance battery in the California market will enable renewable-power systems and energy storage systems to more effectively reduce peak demand on the electric grid, directly benefiting ratepayers. Potential energy and cost savings to ratepayers would result from reducing transmission losses in electricity delivery and extending both the service life of grid-system equipment and the time period between grid-system upgrades. In addition, environmental impacts of the California electricity supply and transmission and distribution system would be reduced. Since the technology is still far from commercialization, it is difficult to estimate the rate at which these benefits would accrue to California ratepayers.

Recommendations:
Further optimization of the polymer coating and more detailed characterization of the mechanism of capacity fading in $LiMn_2O_4$ cathodes during cycling and storage at elevated temperatures are needed. The researcher should consider the following recommendations upon commencement of additional work in this area:

1. Reinvestigate the relationship between the capacity and thickness of the polymer layer. Perhaps there should be a stronger relationship.
2. Refine the cathode coating method, specifically, initial powder dispersion and mixing procedure.
3. Determine the optimal amount of PDDA that will yield maximum stability of the modified cathode.
4. Draw a comparison of charge/discharge cycling results (after multiple cycles) for the untreated cathode versus the treated cathode. Investigate other performance parameters, e.g., charge/discharge rate, diffusion constant, etc.
5. Investigate further the mechanism of capacity fading during cycling and storage at elevated temperatures. Establish the nature of the cathode surface film formed following the potential cycle.

6. Develop new image-processing techniques for studying the local changes in cathode-surface topography.
7. Quantify reductions in manufacturing costs for spinel lithium-ion batteries as a result of using surface-modified $LiMn_2O_4$ cathodes.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Integral Catalytic Combustion/Fuel Reforming for Gas Turbine Cycles

EISG Grant Number: 99-21
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Greg Jackson (301) 405-2368
Organization: University of Maryland
Grant Amount: $74,992
Status: Completed

Project Description:
The purpose of this project was to establish the basis for developing an integral catalytic combustor/steam reformer for producing H_2-rich reformate from natural gas while providing low nitrogen oxides (NO_x) air to a gas turbine. Applications include stabilization of ultra-low NO_x gas turbine combustors, pre-reforming fuel for solid oxide fuel cells, and consuming hydrogen-rich anode off-gas. Through solid-state heat conduction the integral catalytic combustor/steam reformer transfers heat from the catalytic combustion catalyst to the reforming catalyst. This reactor design allows combustion at high equivalence ratios and very high heat transfer rates to the reforming catalysts. These conditions enable conventional steam reformers to operate at standard temperatures, below 800°C. In this project the researcher optimized combinations of combustion and reforming catalysts in a laboratory-scale, flat-plate reactor. The researcher tested the catalyst combinations at atmospheric pressure to assess reactor operability.

These tests were also used to validate numerical models with detailed chemistry to establish the basis for reactor design and performance at the high-pressure conditions expected in actual applications. The project objectives included the development of a prototype reactor from these initial efforts. However, challenges in identifying stable catalyst combinations in the flat-plate reactor tests delayed the project and the prototype reactor was not built. Nonetheless, the project results provide a solid basis for the design and testing of a prototype reactor for ultra-low emissions combustion systems for gas turbines and fuel cell applications.

The researcher focused on the assessment of catalysts, design approaches, and reactor operability. The assessment was performed through the flat-plate reactor tests and numerical models validated with the flat-plate reactor data. The flat-plate reactor provided a simple geometry for assessing catalyst performance and heat transfer data to determine the necessary features of a full-scale reactor design.

Proposed Outcomes:
The goal of this project was to determine the feasibility of an integral catalytic combustor/steam reformer for producing hydrogen gas (H_2) rich reformate for ultra-low NO_x gas turbines from natural gas. The researchers established the following project objectives:

1. Identify preferred reliable catalyst combinations.
2. Test selected catalyst combination in flat-plate reactor to assess reactor performance.
3. Develop models for integral catalytic combustor/reformer design and operability.
4. Assemble and test a sub-scale prototype of integral reactor at high-pressure conditions.
5. Analyze reactor performance in advanced fuel cell/gas turbine cycles.

Actual Outcomes:

1. The researcher determined that high-activity reforming catalysts are needed (Rhodium (Rh)-based supported catalysts) to minimize the risk for thermal runaway of the catalytic combustion process. The high-activity Rh-based reforming catalysts

provide adequate rates for endothermic steam reforming on one side of the reactor wall to permit catalytic combustion at relatively high fuel/air ratios. Without the heat transfer to the reforming catalyst, the catalytic combustion at high fuel/air ratios could result in over-temperature on the combustion catalyst surface. Rh-based reforming catalysts provide the necessary activity to sustain high conversion of methane (CH_4) to H_2 at temperatures < 800ºC and thereby control combustion catalyst temperatures. Paladium (Pd) catalysts were chosen for the combustion side.

2. Flat-plate reactor tests demonstrated enhanced operability and low-temperature performance with H_2 combustion in comparison to CH_4 combustion using the preferred Pd-based combustion catalysts. These tests were performed with Rh reforming catalysts in the same reactor. For gas turbine applications, experimental results suggest the use of an integral reactor to convert a fraction of a CH_4 fuel stream to H_2/carbon monoxide (CO) would require a higher temperature combustion catalyst. However that catalyst should be less prone to deactivation than conventional Pd-based catalysts and require less low-temperature activity for reactor start-up.
3. The numerical model established the operating parameters for operation under high-pressure conditions.
4. No prototype reactor was built. The researcher ran into time and fund constraints.
5. The results establish the potential for the integral reactor for sustaining catalytic combustion at low temperatures and for providing good volumetric efficiency for H_2 production.

Conclusions:

1. The researcher identified an effective catalyst system for the integral steam reformer/catalytic combustor. The cost of the Rhodium catalyst may limit application of this system.
2. The integral reactor is well suited for burning fuel cell anode exhaust in fuel cell/gas turbine cycles.
3. The numerical model is available for commercial developers.
4. The next advance of this technology must include building and testing a prototype reactor.
5. The flat-plate reactor experiments and the associated numerical models identified the ratio of moles of combustion fuel to moles of reforming fuel necessary to establish reliable steady-state reactor performance within catalyst temperature limits. The results also indicate the best reactor design would involve a co-flow system where the high combustion and reforming rates occur near the entrance to the reactor.

Benefits to California:

The ultimate success of this project in demonstrating operability of an integral reactor with stable catalyst temperatures for gas turbines with ultra-low emissions may provide a unique approach for gas turbines within California to set new "Best Available Control Technology" (BACT) standards. Successful development of the proposed integral catalytic combustor/steam reformer for natural gas will also provide technical expertise within the State for the emerging areas of solid oxide and molten carbonate fuel cell power plants. While it is difficult to quantify the future market for high temperature fuel cells and ultra-low emission gas turbines, it is clear that ultra-clean power generation will be required in California by 2007. The development of the integral reactor concept may provide a critical enabling technology for those power plants.

Recommendations:
Development of a prototype integral catalytic combustor/steam reformer for natural gas was not completed as proposed, but the project results and the design tools developed in this project provide the basis for completion. The experimental and numerical results establish the reactor as a viable approach for burning fuel cell exhaust to make additional H_2 for fuel cell operation. Based on the outcomes from this preliminary evaluation of this reactor concept, recommendations for further development are:

1. Demonstrate a prototype reactor at pressures of 5 atmospheres (atm) or higher.
2. Investigate the possibility of using new Pd-doped hexa-aluminate catalysts for operating temperatures > 900ºC with CH_4 as the combustion fuel.
3. Test for durability of preferred catalyst combinations at operating conditions.
4. Develop a reactor operation strategy for fuel cell/gas turbine power plants and more conventional gas turbine power plants.

Project Status:

- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Completed.

Method of Improving Efficiency of Combined Cycle Power Plants

EISG Grant Number: 00-28
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Robert Surette (323) 669-0072
Organization: Energy Constructs
Grant Amount: $63,500
Status: Completed

Project Description:
Large (>200 megawatt (MW)) gas turbine combined cycle power systems are the primary choice in California for new utility-scale power generation facilities. The cost of fuel for these systems is over 80% of their operating expense. While system efficiencies are often over 50%, any further improvement in engine efficiency reduces both the cost of the power and the emissions generated per megawatt-hour. Engineers note that turbine exhaust backpressure is a significant source of efficiency loss in gas turbine combined cycle (GTCC) power plants. Poor aerodynamics in the transition section between the gas turbine and the heat recovery steam generator (HRSG) is the source of this backpressure.

The cost of electricity generated by GTCC power plants is dependent on the heat rate of the engine system and cost of natural gas. If the heat rate is reduced (less fuel is used to generate each megawatt-hour) the cost to produce electricity will decline. The cost of electricity generated by GTCCs is in the range of 3.0 to3.7 cents/kilowatt hour (kWh) depending on system efficiency. A 0.5% increase in system efficiency (for the most efficient systems) could reduce electricity costs by 0.028 cents/kWh, saving Californians up to $18 million per year. Savings are based on all GTCCs in operation or under construction in the State being fitted with the ejector-diffuser. Dynamic pressure recovery in turbine exhaust nozzles, which are subsonic, is limited by the onset of flow separation at an area ratio of the order of 1.5 to 1. By adding an ejector-diffuser, the total expansion ratio can be doubled without flow separation. Additionally, the ejector-diffuser can function as a suction pump that can be used to modify the boundary layer separation experienced in the transition section of the HRSG. The approach taken by this project was to quantify the benefits of the ejector-diffuser installed in the flow path between the exhaust diffuser of a straight-through gas turbine and the HRSG of a combined cycle power plant. The ejector-diffuser improves the aerodynamics and thereby reduces the backpressure on the gas turbine engine. Basically, the innovation is an annular plenum with ports to the exhaust flow. It surrounds the conventional exhaust diffuser. No air or steam flows through the plenum. The researcher proposed using computational fluid dynamic (CFD) modeling to model the ejector-diffuser in the flow duct in an effort to increase the stable expansion ratio and to improve the flow distribution. Prior one-dimensional analysis indicated savings on the order of 0.5 percent. The purpose of this study was to quantify accurately the savings, using state-of-the-art CFD analysis incorporating three-dimensional viscous flow, and separation phenomena.

Proposed Outcomes:
The goal of this project was to determine the feasibility of increasing GTCC efficiency by 0.5% using an ejector-diffuser to reduce the pressure losses in the transition section between a gas turbine exhaust diffuser and the heat recovery steam generator. The researcher established the following project objectives:

1. Demonstrate a reduction in backpressure at the gas turbine exit plane of 4 inches of water when compared with the conventional turbine to HRSG transition section (typically 12 to 16 inches of water). Backpressure reduction leads directly to engine efficiency improvement.

2. Demonstrate the potential for stabilizing the boundary layer in the transition section of the HRSG with the new technology. Flow separation should be reduced or eliminated to increase the turbine adiabatic expansion ratio. An increased expansion ratio leads to lower turbine backpressure.
3. Demonstrate an overall improvement in efficiency of 0.5% or more.

Actual Outcomes:

1. Calculations demonstrated backpressure reduction at the exit plane of the gas turbine to be over 4 inches of water.
2. The researcher demonstrated that the flow path more closely followed the duct walls resulting in an increase in the adiabatic expansion ratio by a factor of two.
3. The researcher demonstrated a 0.5% engine efficiency improvement.

Conclusions:

1. A properly designed ejector-diffuser can significantly improve the flow characteristics into the transition duct of a combined cycle gas turbine system. The diffuser increases the adiabatic expansion ratio by a factor of 2, which allows the nozzle exit plane pressure to decrease by about 4 inches of water.
2. The addition of a suction surface to the transition section causes the flow to follow the upper surface of the duct and therefore increase the turbine adiabatic expansion ratio. More work is required to investigate duct changes to induce the flow to turn the corner in the transition duct.
3. All gas turbine engines are sensitive to nozzle exit-plane backpressure. A 4-inch drop in exit pressure can produce a 0.5 percent increase in engine efficiency in the GE Frame 7FA engine. Ejectors can produce high levels of noise. This adds to the problem of noise reduction in any combined cycle plant. The researcher did not comment on this issue.
4. The researcher did not estimate the incremental capital and operating costs of adding ejectors. The device appears to be relatively simple to implement.

Benefits to California:

If the ejector-diffuser concept demonstrated in this project was applied to all large gas turbine combined cycle power plants operating or under construction in California, ratepayers would save from $6 million to a maximum $18 million per year. Maximum beneficial savings are based on 8000-hour annual operation. A GTCC typically runs less than 4000 hours/year. Savings would increase as more GTCCs are licensed in the State. Air quality would improve because less fuel would be consumed to produce the same amount of electricity. With lower demand for natural gas, prices for that commodity could be less volatile.

Recommendations:

A physical demonstration is required before significant interest can be generated in the optimized ejector-diffuser. The Program Administrator recommends a cold test in a model test facility as a first step of verifying the CFD model results. Upon successful completion of that test, the researcher should work with a real project and perform a hot test. The potential benefits of this research are great enough to continue public funding of the project through the cold test phase. At that point an HRSG manufacturer or a turbine manufacturer should begin to participate in the hot testing and commercialization of this technology.

The researcher should estimate the cost to build and operate an ejector-diffuser in a GTCC system.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Omni SmartPump

EISG Grant Number: 99-12
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Bernie MacDonald (707) 937-4352
Organization: Omni Instruments
Grant Amount: $75,000
Status: Completed

Project Description:
Current agricultural irrigation methods are energy inefficient. These methods use alternating current (AC) motors ranging from 50 to 80% efficiency to drive water pumps for water spraying or flooding methods that use twice the water needed. Hence moving this volume of water takes twice as much energy as is needed for water-efficient drip irrigation systems. Current drip irrigation systems that use single speed AC motors employ inefficient on/off cycling or complex and inefficient constant pressure plumbing strategies to maintain the required pressure. This project researched the application of high efficiency, variable-speed direct current (DC)-motor powered water pumps to drip irrigation systems to more efficiently achieve the optimal pressure needed. Such systems promise significant improvements in power use, water use, and labor costs in a wide range of agricultural scenarios.

The project focused primarily on the development of a grid powered high efficiency variable-speed DC motor capable of drip irrigating a 2-8 acre area. A secondary objective was to design the DC motor so that it could also be powered by renewable energy sources such as solar panels or wind generators that would charge a battery bank to support intermittent irrigation use. The project identified irrigation pump requirements, purchased compliant 150 gallons per minute (GPM) commercial centrifugal pumps, and designed and constructed 5 horsepower rare-earth permanent magnet blushless direct current (PMBLDC) motors mechanically configured to mate with the pumps. These units were designed and configured to maintain output pressure through a commercial transducer coupled to motor speed control circuitry.

The project assembled and tested four (4) systems. The DC powered drip irrigation systems ran reliably up to 40% of rated power for electro-magnetic and system functional evaluation. At higher power levels, the output switching devices (metal-oxide semiconductor field-effect transistor (MOSFET)) in the control circuitry failed catastrophically. This failure will require redesign of controller circuitry and incorporation of newer more robust switching devices, which are currently reaching the market. Although testing was stopped by the controller problems, the data generated from laboratory testing below 40% rated power was encouraging.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using a variable speed DC motor in a drip irrigation system to achieve greater energy efficiency. The researcher established the following project objectives:

1. Determine the optimum size of an irrigation area on which to use a drip irrigation system having pressure controlled by a variable speed DC motor.
2. Design a 2 HP DC pump system that can be manufactured for $250 or less.
3. Incorporate into the design the capability to power the DC motor with a photovoltaic or wind turbine system with a battery bank that would sell for under $2,000.

4. Demonstrate reliable operation over the entire range of rated power.
5. Demonstrate a reduction in energy consumption of at least 30% over existing, single speed AC motor-driven drip irrigation systems.

Actual Outcomes:

1. The researcher determined a drip irrigation system needed to be capable of supporting an area of 2-8 acres.
2. The researcher concluded a 5 HP DC motor/pump system was needed to irrigate an area up to 8 acres in size. A 5 HP prototype system including the motor, controller, and pump was designed, fabricated, and tested. The project objective of demonstrating a system with a manufacturing cost of $250 or less was not met since the prototype motor failed above 40% load requiring a redesign. Redesign could impact the system manufacturing cost.
3. To prove this objective the researcher had to show that the DC motor/pump could be produced and sold for $500, and the renewable energy system could be added for less than $1500. Since the researcher was not able to show that the DC motor/pump could be produced and sold for $500, this objective was not met.
4. The output switching devices (MOSFET) in the control circuitry failed when operated above 40% of the rated power.
5. Due to motor controller failure above 40% rated power the prototype system was unable to demonstrate the projected energy savings of 30 to 50%. Below 40% rated power the prototype motor/pump system operated at 70-80% efficiency, which is only marginally better the 65% to 75% efficiency of the baseline single speed AC motor using on/off operation to maintain pressure.

Conclusions:

The researcher failed to prove the feasibility of developing a variable speed 5 HP DC motor/pump system for a drip irrigation application. The limited success of the prototype motor under partial load was encouraging but not sufficient to draw any firm conclusions about the potential for commercial success. Other conclusions are:

1. The researcher's conclusion that the proposed system would need to be capable of irrigating up to 8 acres was based on the size of a traditional farm plot, availability of appropriately sized 42-volt DC motors, and installation costs. The conclusion appears to be justified and sufficiently supported.
2. The proposed design of the 5 HP DC motor and controller has serious design flaws that cause catastrophic failure of the motor controller above 40% load. The researcher was unable to determine the exact cause of the failure leaving open the possibility that the problem is either centered in the motor controller circuit or is related to an interaction between the new motor design and control circuit. A redesign of the control circuit and possibly the motor design as well will have an unknown impact on the projected cost of the system. As a result, no firm system cost estimate can be made at this time. The researcher believes that recent advances in fuel cell automobile systems will provide the necessary low-cost solutions to the technical problems encountered that will eventually allow the system to be manufactured for $250.
3. The researcher's claim that the proposed motor/pump system could be purchased and powered by a small renewable energy system for $2,000 was only partially supported. The Program Administrator concurs that a small renewable energy system could be installed for the projected $1,500 cost that would be sufficient to pump 6000 gallons in one hour with a less than 10-foot lift, once a day. However, the projected manufacturing cost of the motor/pump system for $250 with a retail cost of $500 was not supported by the project findings.

4. System reliability is extremely important in any commercial irrigation system. A farmer cannot afford to install an irrigation system that might not sustain his crops. This issue must be addressed before the proposed system can be commercialized.
5. No firm conclusion can be drawn regarding energy savings based on the proposed system design. The researcher claimed some limited energy savings when the prototype motor operated under partial load in a laboratory setting but the type of data collected was not sufficient to support any solid claims in this area. No field-testing was conducted under actual operating conditions.

Benefits to California:
It is difficult to quantify the overall beneficial savings without serious market projections, but individual user savings can be quantified and extended into the larger market. A single user would accrue a minimum reduction of 2 kWh/day and a water savings of 6000 gallons, every 2-day watering cycle, which accrues to 180 kWh and 540,000 gallons of water in a 6 month season. A conservative estimate would be 100 kWh and 100,000 gallons per season. This in itself would be of real value and would be compounded if local power generation (solar, wind) were utilized. On a smaller scale, a farmer may be able to purchase 300 watts of solar panels with batteries for $1500 to $2000 to completely remove this energy load from the grid. That system could generate, store, and apply up to 2 kWh per day of energy to irrigate over 10 acres with no other energy inputs.

In a larger sense, because it removes this energy load from the grid, all Californians benefit when a renewable energy powered water transport system is available to fill the needs of agricultural irrigation and other related water needs. In addition to irrigation, the pump system developed in this project could fill other needs requiring efficient water movement in areas that have limited grid power availability.

Recommendations:
The Program Administrator has determined that the project failed to prove the feasibility of using high-efficiency DC motors for driving drip irrigation pumps to reduce electricity use in agricultural applications. The fact that the prototype system was able to operate efficiently up to 40% rated power is encouraging but insufficient to establish technical or commercial feasibility. The Program Administrator recommends that any future R&D development of this concept be contingent upon addressing the following concerns:

- Identify the exact cause of failure above 40% load and redesign the motor controller and motor, if necessary.
- Show evidence of a clear market connection by teaming with a motor/ pump manufacturer.
- Substantiate the energy savings of the variable speed DC motor over existing variable speed AC motors that could be adapted to drip irrigation systems.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Omni-Directional Insect Eye Concentrator Using a Hyper-Spectral Photovoltaic Cavity Converter (PVCC)

EISG Grant Number: 00-13
PIER Area: Renewables
Principal Investigator: C. Wood Hays (760) 744-2575
Organization: United Innovations, Inc.
Grant Amount: $74,992
Status: Completed

Project Description:
California's potential to generate electricity using solar photovoltaic (PV) technology is enormous. High first cost continues to limit rapid deployment of this technology. It is very important to reduce the consumer's first cost of solar electricity (currently around $6/watt installed) to encourage greater deployment of solar PV generation. In addition, recent legislation demands that investor-owned utilities provide 20% of their power from renewable sources by 2017.

The objective of this project was to develop a low-cost solar photovoltaic concentrator to achieve solar concentrations of 50 suns. The solar collector was modeled on omni-directional insect eye optics. Minimal tracking requirements were anticipated. The researcher projected the new solar concentrator optics would require fewer highly efficient solar cells than non-concentrating systems. This could mitigate the otherwise unacceptably high cost of current efficient cells. The associated receiver optical system is much less expensive than the solar cell materials it would replace. The researcher projected a reduction in cost for PV systems to less than $3/watt upon successful completion of this project. The proposed concept combined omni-directional "insect eye" optics with a photovoltaic cavity converter (PVCC). A spectral splitting process inside the PVCC used Rugate filters deposited on high-efficiency solar cells to maximize the use of the available solar spectrum and to boost conversion efficiency. Commercial and residential rooftop applications are the anticipated final target of this project.

The PVCC module contained an array of discrete concentration/conversion units that operated independently. These units were electrically connected in series and in parallel to achieve the required open-circuit voltage and short-circuit current for the module. Each unit had upward-looking multi-facetted optics that resembled the compound eye of an insect. Each individual facet concentrated the solar flux and injected it into a spherical cavity shared by all facets in the PVCC module. The assembly of the facets collectively provided a large acceptance angle for each insect eye that minimized or eliminated tracking requirements. The spherical cavity (PVCC) contained the cells that were attached to its interior surface. The PVCC trapped the concentrated light it received from all facets in that unit and split the solar spectrum into discrete frequency bands. The cells inside the cavity consisted of four different groups, all from the III-V family. The spectral response of each group is different, but together they span the solar spectrum. Each cell group was covered with a conjugate Rugate filter that screened the photons, so that the photons with matching energy (frequency) passed directly to the detector, and the remainder were reflected. This "spectral screening" process inside the cavity optimized the conversion efficiency, as it allows the photons to be captured in the proper cells with full utilization of the solar spectrum**.**

Proposed Outcomes:
The goal of this project was to prove the feasibility of using multi-faceted optics as a solar concentrator and an optical cavity containing multiple, spectrally selective (Rugate) filters to

economically capture portions of the solar energy, sending each portion to a detector tailored to a specific frequency range. The overall goal was to develop a solar energy conversion device with very high efficiency and low cost. To accomplish this goal the researcher established the following objectives:

1. Create an optical system with a Photon Utilization Factor (PUF) in the cavity greater than 0.9. The PUF is the probability of a photon entering the cavity to be captured in a matching converter cell.
2. Select four candidate materials from those in the III-V group that span the solar spectral range for the sub-cell photon converters.
3. Achieve composite field of view of +/- 30 degrees and light throughput efficiency of the facetted insect eye optics of at least 80%.
4. Achieve solar flux concentration ratio inside the cavity greater than 30 suns.
5. Determine the optimum operational cell temperature.
6. Achieve overall performance of the proposed system of >38% @ 25^{o} C.
7. Develop a low-cost manufacturing process to achieve system costs of less than $3/watt.

Actual Outcomes:

1. The researcher measured the Photon Utilization Factor (PUF) in the cavity at 0.806.
2. The researcher identified four candidate materials (III-V) for the sub-cells: InGaP, GaAs, InGaAsP, and InGaAs. (In-Indium, Ga-Gallium, As-Arsenic, P-Phosphorous) Their transmission frequency bands are, respectively, 350-650 nm, 650-850 nm, 850-1050 nm, and 1050-1800 nm.
3. Maximum composite field of view was +/- 30 degrees off normal. Light throughput efficiency of the facetted (insect eye) optics was 63%.
4. Highest solar flux concentration ratio inside the cavity was just over one tenth of a sun, that is, it was 0.11 suns.
5. The researcher determined the operational cell temperature to be 65^{0} C @ 25^{0} C and 50 suns.
6. The researcher calculated the overall performance of the system at 22.27 % @ 25^{0} C and 50 suns.
7. The researcher provided insights into potential low-cost manufacturing steps for the system. They included nickel electroforming for the faceted optics. For the cavity, the researcher suggested spin forming of aluminum.

Conclusions:

1. While not meeting the stated objective, the researcher was successful in achieving relatively high PUF.
2. The researcher identified four materials that span the spectral range necessary to achieve high photon-conversion efficiencies.
3. The researcher met this stated objective for the optical field of view.
4. The maximum solar concentration achieved was vastly lower than the objective. This discrepancy was caused by a physical mismatch of the concentrating optics and the receiver cavity. Continuing R&D to achieve the objective of 30 to 50 sun concentration would be considered high risk R&D.
5. The researcher met his stated goal of determining the optimum operational cell temperature.
6. The overall system performance was impaired by the lack of solar concentration. Calculations showed that the photovoltaic converter cavity with the four sub-cells could operate at a cavity efficiency of 47%. The researcher also calculated the efficiency for a total solar system using his photovoltaic cavity converter and a tracking dish concentrator at 38%. If this efficiency could be achieved in practice it would be a major success.

7. Without the benefit of multifaceted optical concentrators, no savings in system cost could be realized. Therefore, the cost of solar electricity could not be reduced with the proposed system. However, there remains the potential that the revised system using a tracking dish concentrator could provide highly efficient and economical solar-derived electricity.

Overall this project did not prove the feasibility of the proposed system as a whole. However, the PVCC unit that converts the concentrated solar energy into electricity worked quite well. Unfortunately the extremely low concentration caused by a geometrical (structural) constraint in the design of the facetted optics represents a major problem. In his final report the researcher proposed coupling his successful, photovoltaic cavity converter to a tracking dish concentrator. The Program Administrator concludes that this could be highly successful.

Benefits to California:
Concentrating solar systems have the potential to provide significant benefits to the ratepayers of California. However the multifaceted optical concentrator in this project did not provide the desired solar concentration. The selective filter receiver (PVCC) may have benefits if coupled to a more effective concentrator. Quantifiable benefits can only be determined once that system is designed and demonstrated.

Recommendations:
The extensive R&D required to resolve the problems involving the facetted optics represent too high a risk and should not be pursued. However, the valuable PVCC knowledge obtained in this project could be used in conjunction with a parabolic dish concentrator to form a Dish/ PVCC system. Such a system circumvents the problem of low concentration in the facetted optics and allows the PVCC conversion approach to reach higher performance. The researcher has received additional funding from a federal agency to pursue that concept. The Program Administrator recommends that Californians interested in the deployment of high-efficiency solar-energy systems monitor the progress of this potentially valuable concept.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

OTM Aided Oxygen Enhanced Combustion

EISG Grant Number: 00-29
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Theodore Tsotsis (213) 740-2069
Organization: University of Southern California
Grant Amount: $75,000
Status: Completed

Project Description:
Modern combustion turbines in California power plants use lean, premixed combustion to significantly reduce air pollution from oxides of nitrogen (NO_X) and carbon monoxide (CO). The flame stability in the combustor limits the degree to which NO_X can be reduced. If the turbine is excessively starved for fuel, it will stop running. Before flame extinction occurs, flame instability causes a phenomenon called "rumble," which results in serious damage to the engine. This introduces a practical lower limit on how lean the fuel-air mix can be, called the "lean limit." That in turn results in NO_X production that cannot be lower than a certain minimum for any given combustion turbine using air as the oxidizer.

California power plants could reduce the creation of NO_X pollutants if the flame stability was improved to produce a lower lean limit. Further, improved flame stability could reduce damaging turbine "rumble" and life-limiting hot spots at the turbine inlet. Since even the cleanest gas-turbine power plants can produce over 200 tons per year NO_X per 500 megawatts (MW), there is a great incentive to reduce the quantity of this pollutant going into the atmosphere. Additionally, improved flame stability can result in high engine efficiency.

Engineers have shown that adding oxygen to the combustion air (oxygen-enhanced combustion (OEC)) results in stable combustion at a lower lean limit. The key challenge facing OEC is the significant cost of oxygen enrichment. This project studied the feasibility of using dense, high-temperature, solid-oxide membranes (oxygen-transport membranes (OTM)) to produce oxygen *in situ,* thus improving the quality of the combustion air. The researcher proposed using high-quality oxygen-transport membranes and waste heat from the exhaust-gas stream to obtain the oxygen.
Modern combustion turbines in California power plants use lean, premixed combustion to significantly reduce air pollution from oxides of nitrogen (NO_X) and carbon monoxide (CO). The flame stability in the combustor limits the degree to which NO_X can be reduced. If the turbine is excessively starved for fuel, it will stop running. Before flame extinction occurs, flame instability causes a phenomenon called "rumble," which results in serious damage to the engine. This introduces a practical lower limit on how lean the fuel-air mix can be, called the "lean limit." That in turn results in NO_X production that cannot be lower than a certain minimum for any given combustion turbine using air as the oxidizer.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using oxygen-transport membranes to produce oxygen *in situ* for use in an OEC combustor for gas-turbine electricity generation. The researchers established the following project objectives:

1. Determine the technical feasibility of coupling oxygen-transport membranes (OTM) with oxygen-enhanced combustion (OEC). Determine stability characteristics of membranes in the OEC environment.
2. Determine the combustion stability of the OTM/OEC hybrid concept.

3. Determine the formation of pollutants, with particular emphasis on NO_X emissions. Quantify the potential for attaining NO_X emissions in the single-digit parts per million (ppm) range.
4. Determine combustion-stability and pollutant-formation characteristics for oxygen lancing. This is one of the techniques industry uses for the implementation of OEC.
5. Determine the potentials of the OTM/OEC technology for improving the efficiency of gas turbines to values in excess of 35%.

Actual Outcomes:

1. The researcher prepared a number of dense solid-oxide oxygen-conducting membranes made of $SrCo_{0.5}FeO_3$ perovskite material, and tested them for oxygen-permeation characteristics. The researcher also tested them under both inert and reactive conditions. The membranes prepared showed satisfactory oxygen permeability and good stability during the permeation studies, both in the presence of inert and reactive sweeps.
2. Oxygen (O_2) addition increased laminar flame speed and, therefore, enhanced flame stability. This was due to the progress of the branching reaction as the O_2 concentration increased.
3. Analysis of the NO_X structures revealed that O_2 enrichment resulted in reduced NO_X production for the same flame temperature. Single-digit NO_X production was not reported. Oxygen addition appeared to limit the emission of other pollutants. Studies of fuel-rich flames, for example, revealed a significant reduction of the maximum CO mole fraction, $(X_{CO})_{max}$, as X_{O2} increases for flames with constant T_{max}. This reduction was due to the interaction downstream of the premixed flame between the fuel-rich premixed and the non-premixed flame.
4. Both theoretical and experimental data showed that oxygen lancing beneficially reduced CO/NO_X emissions when oxygen-enhanced and non-enhanced tests were run with the same maximum flame temperature.
5. Design calculations indicated that turbine efficiencies as high as 46% can be achieved through the implementation of OTM/OEC technology. The degree of improvement is difficult to discern, since the efficiency of the engine under evaluation appeared to be between 42% and 43% before the addition of the OTM/OEC technology.

Conclusions:

1. These membranes are highly permeable to oxygen under conditions similar to those in the OEC combustion environment. The researcher showed oxygen permeability of these membranes under reactive conditions to be significantly higher than those attained in inert environments.
2. Results on flame propagation demonstrated that oxygen enrichment could enhance combustion stability: the same flame temperature increased laminar flame speeds and extended flammability limits. This was caused by the effect of oxygen concentration on the main branching reaction $H+O_2 > OH+O$. Under certain enriched conditions, the researcher found that oxygen addition acted as a heat sink to reduce flame temperatures. Higher oxygen concentration also increased laminar flame speed, thus enhancing the progress of the branching reaction.
3. Analysis of the NO_X structures revealed that oxygen enrichment can reduce NO_X production for the same flame temperature. Lower NO_X production is caused by the synergistic effect of reduced flame temperature and reduced nitrogen (N_2) concentration.
4. The researcher found a significant reduction of the maximum CO mole fraction, $(X_{CO})_{max}$, as X_{O2} increased for flames with constant T_{max}. The researcher hypothesized that this reduction comes from the interaction between the fuel-rich premixed and the non-premixed flame established downstream of the premixed flame. More specifically, the

reduction of the equivalence ratio required to maintain a constant T_{max} as X_{O2} increases, is responsible for the reduction of both $(X_{CO})_{max}$, and $(X_{NOx})_{max}$.

5. Design calculations indicated that turbine efficiency increased with the degree of oxygen enrichment. That depended on the quality of membranes utilized. Membranes with poor separation characteristics or lower permeability showed poor performance, as their operation required additional energy beyond the available waste heat. In fact, use of inferior-quality membranes was likely to result in a decrease in turbine efficiency.

Oxygen-enhanced combustion is a proven technique. This project was undertaken in order to prove the feasibility of using oxygen-transport membranes to produce oxygen *in situ* for use in oxygen-enhanced combustion for gas turbines. The fundamental feasibility of this concept has been proven. OTMs can function in conditions similar to the OEC environment. It remains to be seen if OTMs can extract a sufficient volume of oxygen from the exhaust stream at a high enough rate to be useful in the gas turbine.

Benefits to California:
The primary benefit to the ratepayer from this research is increased affordability of electricity in California. The researcher projects at least a 1.5% increase in the efficiency of gas turbines and a 20%–60% decrease in NO_X emissions for those turbines using lean, premixed combustion. The baselines for these estimates are not clear, therefore it is not possible to estimate the overall impacts on the California ratepayer.

Other researchers have shown that oxygen-enhanced combustion in gas-turbine engines results in higher turbine efficiency or lower levels of NO_X and CO emissions. This study demonstrated that similar results can occur when high-quality oxygen-transport membranes and waste heat are used to obtain the oxygen from the exhaust-gas stream. This could benefit the ratepayer through a low-cost implementation of oxygen-enhanced combustion resulting in higher turbine efficiency or lower levels of regulated emissions.

Recommendations:
The use of solid-oxide membranes in power-generation applications has been proven technically feasible. In order to bring the technology to the commercial stage the following tasks should be conducted:

1. Develop inexpensive, tubular, solid-oxide membranes and demonstrate the OTM/OEC concept in a scaled-up membrane reactor/combustor configuration.
2. Test the long-term (>1 year) stability of tubular membranes.
3. Carry out an extensive economic evaluation of the technology, including a detailed market survey.

After taking into consideration: (a) research findings in the grant project, (b) overall development status, and (c) relevance of the technology to California and the PIER program, the Program Administrator has determined that the proposed technology should be considered for follow-on funding within the PIER program. Receiving follow-on funding ultimately depends upon: (a) availability of funds, (b) submission of a proposal in response to an invitation or solicitation, and (c) successful evaluation of the proposal.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Polymer-Zeolite Nanocomposite High-Temperature Proton-Exchange-Membranes for Fuel Cells

EISG Grant Number: 00-31
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Yushan Yan (909) 787-2068
Organization: University of California, Riverside
Grant Amount: $75,000
Status: Completed

Project Description:
Natural gas fueled gas turbine combined cycle power plants are the primary choice for new power plants in California because they can achieve much higher thermal efficiency and lower air emissions than coal- or distillate-fired units. Reducing pollutant emissions of nitrogen oxides (NO_x), and carbon monoxide (CO) to meet California's increasingly stringent air quality regulations remains a significant concern. Advanced generation technologies that improve efficiency and significantly reduce NO_x, CO and carbon dioxide (CO_2) emissions are in demand. Proton Exchange Membrane (PEM) fuel cells are potential candidates for residential distributed power production. Nafion is the most commonly used proton-exchange membrane in PEM fuel cells, but its economic viability faces significant technical roadblocks. Among these problems are: water management at the electrodes; CO poisoning of the anode catalyst; slow cathode kinetics; and the high cost of the platinum electrode catalyst.

If these difficulties were solved, PEM fuel cells could be used for added generation capacity both in distributed generation and at the central power plant. Cells using pure hydrogen produce almost zero regulated emissions, only water and heat. Additionally, Carnot's principle, which applies to and limits all heat engines, does not affect fuel cells because the electricity is generated by an electrochemical reaction.

Figure 1 illustrates the use of a PEM fuel cell in a residence. Lower energy use and a cleaner technology will reduce emissions. Actual reductions will vary depending on the air-pollution baseline in any given area.

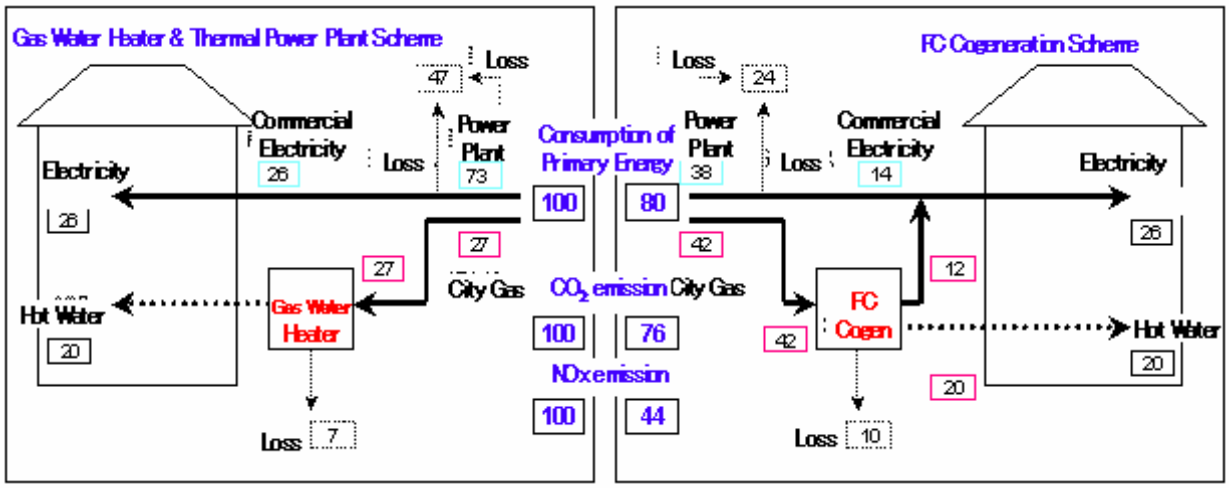


Figure 1. The left side shows a conventional combination of gas-heated water and grid electricity from a thermal power plant. The right side introduces cogeneration into the system by means of a proton-exchange-membrane (PEM) fuel cell. The expected benefits include reductions of 20% primary energy consumption, 24% CO_2 emission, and 56% NO_x emission.

The researcher in this project predicted that the problems associated with Nafion membranes could be eliminated or alleviated once the operating temperature of the PEM fuel cell exceeds 100°C. Above boiling point, water would not flood the cathode and thus prevent the oxygen from reaching the cathode catalyst. On the other hand, Nafion is an excellent proton conductor only when it is fully hydrated. To achieve a 100°C operating temperature, the researcher proposed using zeolite nanoparticles as an additive to Nafion to improve its water retention and cited several published research papers suggesting that zeolites functionalized with sulfonic groups will have comparable or superior proton conductivity to Nafion at high temperatures and low humidity. Because the local hydration and proton conductivity within the nanoparticles should be higher than in Nafion, the researcher hypothesized that the bulk properties of the Nafion with the nanoparticles would improve. The researcher suggested that nanoparticles would interrupt the host matrix less than micron-sized particles and result in improved mechanical properties of the host.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using a zeolite nanoparticle additive to Nafion to improve its water retention and proton conductivity at high temperatures (120 – 150°C). The researcher established the following project objectives:

1. Synthesize mono-disperse zeolite X and/or Y nanocrystals with diameters controlled between 15 to 80 nm in diameter. Prepare uniform Nafion-zeolite X and/or Y nanocomposite membranes.
2. Demonstrate higher water adsorption capacity and proton conductivity in the Nafion-zeolite nanocomposite membrane at high temperatures (120 – 150°C) than those properties of the bare Nafion membranes at 80 °C.
3. Show that a PEM fuel cell system will be over 40% efficient with a 20% reduction of primary energy consumption and 24% and 56% reductions of CO_2 and NO_x emissions, if the proposed high-temperature membrane is successfully developed and integrated into a fuel cell system.
4. Show that the projected cost of a PEM fuel cell power system will be reduced to $600 to $700/kW from the current +$1000/kW if the proposed high-temperature membrane is successfully developed and integrated into a fuel cell system.
5. Formulate a Nafion bi-functional silica nanocomposite membrane and test for water adsorption and proton conductivity.

Actual Outcomes:

1. The researcher synthesized zeolite Y nanocrystals with a mean diameter of 32 nm and developed a new fabrication method that avoids agglomeration of the particles. The researcher prepared Nafion-zeolite Y nanocomposite membranes with 10% by weight zeolite loading.
2. The Nafion-zeolite nanocomposite membrane had slightly higher proton conductivity at 80°C than recast bare Nafion at 80°C. No tests were reported in the 120-150°C range.
3. Although the researcher's proposal cited work done by Tokyo Gas Company to demonstrate this objective, the work was apparently not augmented to evaluate efficiency and emissions objectives during the performance of this project.
4. The researcher did not address the potential cost reduction of a PEM fuel cell system based on the data generated in this project.
5. The researcher formulated a Nafion bi-functional silica nanocomposite membrane. Water adsorption and proton conductivity of the Nafion-silica material were somewhat superior to bare Nafion. The researcher hypothesized that the Nafion-silica nanocomposite membranes could maintain high water uptake at high temperatures.

Conclusions:
The researcher in this project provided a new approach to reducing the cost of a PEM fuel cell by extending its operating temperatures. The data, while suggestive, do not appear sufficient to prove the feasibility of the concept.

1. Zeolite nanoparticles with a mean diameter in the range 15 to 80 nm can be fabricated and uniformly distributed in a Nafion membrane.
2. This project set no precise goals for water adsorption and proton conductivity. Its gains were minor but encouraging. Since no testing was reported in the 120 – 150°C range the Program Administrator cannot determine if the objective was met.
3. The researcher did not present any new information that would support claims of reduced power consumption and emissions.
4. Because the researcher did not provide any information, the Program Administrator cannot speculate on the possible cost reductions of PEM fuel cell systems.
5. Nafion with silica nanoparticles may offer promising high-temperature properties for PEM fuel cells.

Benefits to California:
The primary potential benefit to the ratepayer of this research would be reduced environmental impacts of the California electricity supply and transmission and distribution system. If the technology evaluated in this project were proven, developed into a commercial product, and applied to a residential energy system, it could reduce primary energy use by up to 20%. Savings result from the use of the fuel cell heat for residential water heating and from the reduction of transmission losses in electricity delivery. Since the technology is still far from commercialization, it is difficult to estimate the rate at which these benefits would accrue to California ratepayers.

Recommendations:
Further optimization and more detailed characterization of the Nafion-zeolite nanocomposite membranes and/or the Nafion-silica membranes are necessary to develop the concept into a commercially viable product. The nanocomposite membranes have to be coupled with appropriate electrodes into the configuration of a membrane electrode assembly (MEA) so that the composite membrane concept can be tested in a fuel cell configuration.

The following questions should be considered before beginning additional work in this area:

1. Is there an advantage to the incorporation of mono-disperse zeolite nanoparticles as used? A distribution of particle sizes could be less expensive.
2. What is the mechanism that causes the nanoparticles to enhance macroscopic proton conductivity in the composite membranes? The particles are likely isolated in the Nafion matrix and therefore disconnected from each other. While local hydration and proton conductivity within the nanoparticles should be higher than in Nafion, it is not clear that these should contribute to increasing the water adsorption or proton transport properties of the bulk composite. The mechanism of proton conduction across the nanoparticle Nafion interface is an important and likely limiting process step that should be examined more thoroughly.
3. Based on the proton conductivity results reported, the conductivities of the Nafion-zeolite membranes are slightly above “recast” Nafion and below that of commercial Nafion. These preliminary results appear not to be particularly promising for a significant improvement of PEM conductivity properties. What are the obstacles and how might they be overcome?

4. What are the economics of powering individual residences with fuel cells? Do the reliability and economics improve when several residences and small businesses are aggregated into micro-grids?

Project Status:

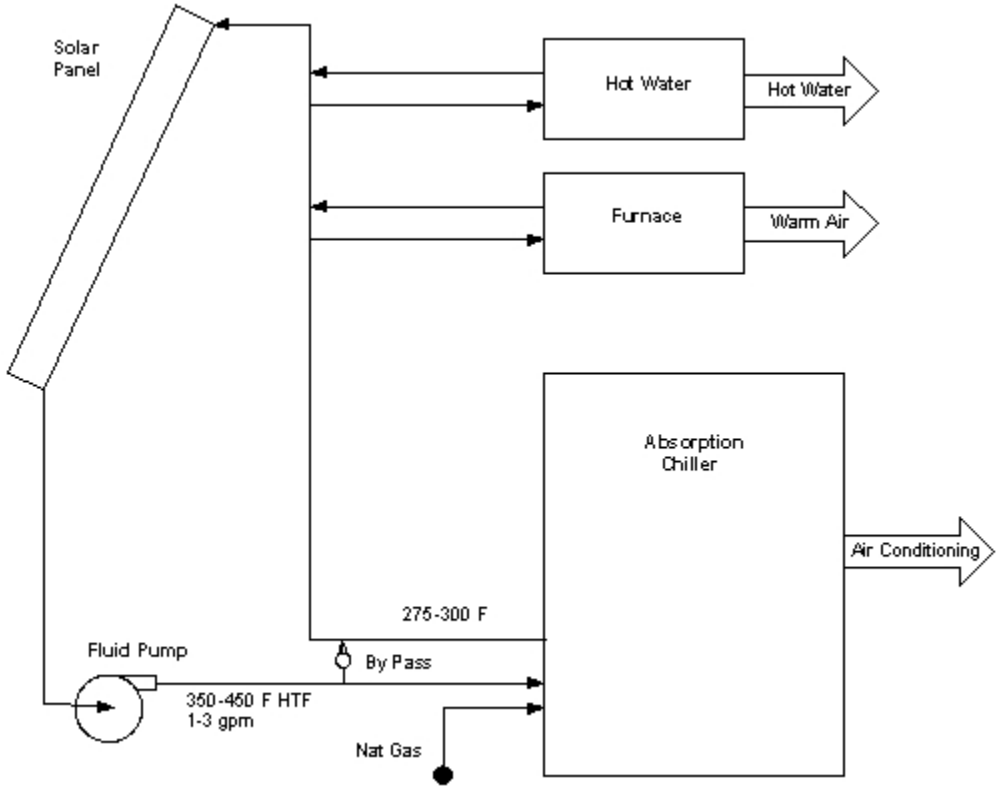
- 100% Completed.
- Completed on Schedule and within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Proof-of-Concept of a Dual-Fired (Solar and Natural Gas) Generator for Use in a Space Cooling System for Residential and Commercial Buildings

EISG Grant Number: 01-06
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Michael A Garrabrant (740) 967-3006
Organization: Cooling Technologies, Inc.
Grant Amount: $75,000
Status: Completed

Project Description:
Many residential and light commercial buildings utilize vapor compression air conditioning technology for space cooling. These devices require significant power (~1.25 kilowatts (kW)/ton depending on size and age of the air conditioning unit) and are large contributors to residential and commercial peak electric demands. According to Department of Energy data, residential buildings in the U.S. consume 1.62 quads for space cooling and virtually all of this energy is supplied by grid-connected electrical equipment. Most metropolitan areas of the U.S. are experiencing significant electric demand and supply imbalance during the summer months due to the increasing use of air conditioning equipment. Solar energy cooling systems would avoid significant amounts of electric energy normally required for space cooling.

Cooling Technologies, Inc. has developed, adapted and tested a new dual-fired (gas-solar) generator for their 5-ton ammonia-water (NH_3-H_2O) air-cooled absorption chiller. The generator is a simple adaptation of their standard gas-fired chiller generator, which minimizes the extra cost associated with the solar/gas product. With dual-fire capability, the need for thermal storage or back-up systems is eliminated. Two prototype generators were developed and tested as part of a breadboard chiller.



Solar HVAC System w/Dual-Fired Absorption Chiller

The system differs from previous solar-powered cooling systems in many respects:

1. Small Size: the system targets the residential, multi-family, and light commercial markets (3-25 Refrigeration Tons).
2. Air-Cooled: the cooling system is air-cooled and therefore does not require expensive and difficult to maintain cooling towers.
3. Dual-Fired: the cooling system is able to operate on either or both solar energy and natural gas or propane, an important feature for practical, affordable systems.

Proposed Outcomes:

The goal of this project was to prove the feasibility of a dual-fuel (solar/gas) generator for a standard 5-ton NH_3-H_2O air-cooled absorption chiller. The specific research goals were the following:

1. Design, fabricate and test a dual-fired (solar/gas) generator for a 5-ton ammonia-water absorption chiller. The design is a modification to the geometry of an existing Cooltec generator in order to minimize product cost.
2. Demonstrate that the heat exchanger is capable of heating the working fluid (ammonia-water) up to an operating temperature of 375 °F, given a solar source temperature of 450°F.
3. Demonstrate that the dual-fired generator, when coupled to the other components of a 5-ton absorption chiller, is capable of producing 5-ton of cooling at the standard ARI conditions (95 °F ambient, 55 – 45 °F chilled water).
4. Operate the breadboard chiller while firing the generator on both simulated solar energy and the combustion of natural gas simultaneously in order to provide guidance for the packaged prototype control system logic specification.

Actual Outcomes:

1. The generator, as tested, is a modification of Cooltec's standard gas-fired generator used as part of their 5-ton chiller by the addition of a heat transfer surface to the outside shell of the generator. The model was verified and calibrated based on the experimental data and can be used to fine tune the generator design for the next development stage.
2. The dual-fired generator prototypes, when fired by hydronic fluid, were able to heat the generator bottom temperature up to the target operating temperature with hydronic inlet temperatures of 460°F and above. Generator temperatures were within 12% of the target at nominal 400°F hydronic temperatures. The prototypes retained their ability to reach full operating temperatures when gas-fired.
3. At 95°F ambient conditions and 55°F return chilled water temperature, the breadboard chiller achieved full cooling capacity with hydronic temperatures greater than 470°F. The measured capacity reduction was 6 and 20% with hydronic inlet temperatures on the order of 450°F and 400°F respectively.
4. The prototype generator was fired using both simulated solar heat and the combustion of natural gas at the same time.

Conclusions:

1. The project team successfully designed, fabricated and tested two dual- fired (solar/gas) absorption chiller generators.
2. The dual-fired generator temperatures were 12% below the target 400°F when "fired" with 460°F hydronic fluid inlet temperature.
3. The breadboard absorption chiller with the dual-fired generator did not achieve full cooling capacity at Air-Conditioning and Refrigeration Institute (ARI) standard conditions.

4. Simultaneous dual-firing of the generator with both simulated solar and gas fuel was accomplished and data was collected. The recorded behavior of the cycle under these conditions provides information required to design the control system for future packaged prototypes.

Benefits to California:
The research project resulted in successful design, fabrication and testing of a solar-fired absorption chiller generator. Since the research and development are based on modifying a commercially available gas-fired 5-ton absorption chiller, the project would likely result in a commercial solar absorption air conditioning unit for large residential, multi-family, and small commercial customers. The estimated incremental production cost for modification of Cooltec's current absorption chiller is $150 to $225 per unit.

The electric energy savings are substantial, reducing space cooling electric load by as much as 75%. Since space cooling is a significant component of electric energy usage in California and as much as 30% of peak demand on a hot, sunny California afternoon, the impact of this system would be great.

Recommendations:
This project has resulted in proven feasibility of the technology. However, additional testing and refinement of the dual-fired generator design are necessary to improve its performance with the absorption cycle. Also a significant amount of development work is necessary for co-firing of the generator with solar and gas simultaneously, particularly with respect to generator burner controls and absorption cycle optimization.

Next step development work should focus on generator performance improvement and co-firing operation. Testing should continue on breadboard with simulated time varying (diurnal) solar energy delivered and cooling load cycling to fine tune absorption cycle and controls.
Following successful performance and co-firing operation, the system could then be field tested, in limited non-critical applications to capture real world performance.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Simple and Reliable Active Power Filter for Energy Efficiency and Power Quality

EISG Grant Number: 00-27
PIER Area: Environmental Area
Principal Investigator: Keyue Smedley (949) 824-6710
Organization: University of California, Irvine
Grant Amount: $75,000
Status: Completed

Project Description:
The electric utility grid generates, transmits, and distributes power with sinusoidal voltage waveforms. When currents flowing in the grid are sinusoidal and in phase with the voltages, the system operates at the highest efficiencies and transmits maximum power. Unfortunately, most electronic loads draw non-sinusoidal currents that introduce harmonics and reactive current into the utility grid. As electronic applications in industry, commerce, agriculture, and residences have increased in recent years, harmonics in the utility grid have become a very serious power-quality issue. Harmonics deteriorate energy efficiency, reduce power transmission capability by 30% or more, cause harmful power disturbances to other appliances on the grid, and lead to potential blackouts. This project focused on the improvement of energy transmission efficiency and power quality via harmonic-current reduction.

The techniques for remedying harmonics can be classified into two groups, passive and active. The passive method involves harmonic trapping using inductors and capacitors. These devices are usually large in size and susceptible to resonance. The active method, known as active power filtering (APF), is based on power electronics and automatic control technology. The advantages of APF include: consistent performance against variable parameters (i.e. no tuning or aging error); the damping of potential resonance; compensating harmonic and reactive power separately or together; and the performance of complex frequency processing not provided by passive filters. When applied to a line with 30% total harmonic distortion, a successful APF will result in the recovery of power transmission capability.

The Principal Investigator proposed building a simple, reliable, and cost-effective APF based on one-cycle control (OCC). This method would eliminate the need of sensing three-phase load current, the nontrivial tasks of calculating harmonics and reactive current components, and the use of multipliers, as required by previous control methods. By applying one-cycle control and sensing the main-line current, this APF can realize unity power factor and low input current with a very simple circuit. The one-cycle control method also has the advantages of operating in constant frequency for reduced magnetic losses and of using space-vector mode for lowering switching losses.

Proposed Outcomes:
The goal of this project was to determine the feasibility of a one-cycle-control, active-power filter to reduce transmission energy loss by 30% and to improve quality by achieving total harmonic distortion (THD)<5% in power lines. The researcher established the following project objectives:

1. Fabricate and test a prototype one-cycle-control, active-power filter capable of 5 kilovolt-amperes (kVA).
2. Demonstrate capability to correct up to 30% THD and to maintain THD <5%.
3. Target manufacturing costs of less than $200/KVA.

Actual Outcomes:

1. The Principal Investigator performed both dynamic analysis and steady-state analysis and design to achieve stable operation. Then he built, debugged, and optimized a prototype OCC-APF circuit featuring one-cycle control with a power capacity of 5 kVA. Dynamic experiments have shown excellent stability.
2. Steady-state tests have demonstrated that the OCC-APF can reduce the THD in the power line from 30% to less than 5% and to maintain it for a wide range of operation at an efficiency of 96%.
3. Cost analysis reflects parts count and 10,000-unit production.

Conclusions:

1. This project designed and built an OCC-APF circuit that is capable of eliminating the harmonics in power-line currents. Its feasibility has been verified by the demonstrated stability and performance. The reliability, maintainability, and cost of the OCC-APF are superior to other proposed APF because of the significantly reduced part count.
2. With a demonstrated ability to correct line-current THD of 30% and maintain a low THD of less than 5%, the proposed OCC-APF provides an excellent solution to the problem of harmonic distortion in California and the US.
3. The Principal Investigator is confident that the target cost of $200/kVA can be met, since the circuit is very simple.

This project demonstrated the feasibility of a one-cycle-control, active-power filter to reduce transmission energy loss by 30% and to improve power quality by achieving total harmonic distortion (THD)<5% in power lines. Preliminary cost estimates indicate that this device is economically feasible.

Benefits to California:

The primary benefit to the ratepayer from this research is reduced environmental impacts of the California electricity supply, transmission, or distribution system. Assuming installation of the proposed devices in 50% of the users, the Principal Investigator reports a total saving of 4.0×10^{15} British thermal units (Btu). The potential environmental benefit is derived by reducing the air-borne emissions from the electric power industry in the United States (according to the statistics of 1999):

- Sulfur dioxide (SO_2): 0.65 million tons.
- Nitrogen oxides (NO_X): 0.4 million tons.
- Carbon dioxide (CO_2): 125 million tons.

According to reports from Electrical Power Research Institute (EPRI), Automated Research Corporation (ARC), Energy Information Administration (EIA) of the Department of Energy (DOE), and Manufacturing Energy Consumption Survey (MECS) at least 10% of the total rated capacity of every electrical substation cannot be used due to reactive and harmonic current flow. The OCC-APF provides a solution by canceling the harmonics and reactive components in the line. At this time there are no devices installed comparable to OCC-APF, since previously proposed systems are too complicated to be reliable and cost effective.

The California Energy Commission reported in a recent study of California industries that the single most potent cause of end-user power-quality problems is voltage sags or swells; the second is harmonics; the third is grounding or wiring issues. Together these three problems account for more than 85% of the power-quality investigations conducted. The study also showed that California has the highest costs in the nation for both outages and power-quality phenomena,

between $13.2 billion and $20.4 billion. While this study does not directly address the cost of harmonics (harmonic distortion), it does indicate that the OCC-APF can eliminate a major contributor to a very large and expensive power problem.

Recommendations:
Based on the success of this research and development, the Program Administrator recommends:

1. Identification of a commercialization partner.
2. Development of a series of full-scale, pre-production, industrial OCC-APFs (10kW~1MW).
3. Field test of the full-scale industrial models.

After taking into consideration: (a) research findings in the grant project, (b) overall development status, and (c) relevance of the technology to California and the PIER program, the Program Administrator has determined that the proposed technology should be considered for follow-on funding within the PIER program. Receiving follow-on funding ultimately depends upon: (a) availability of funds, (b) submission of a proposal in response to an invitation or solicitation, and (c) successful evaluation of the proposal.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Solar Fired, Compressor Assisted Absorption Chiller

EISG Grant Number: 99-15
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Jim Bergquam (916) 383-9425
Organization: Bergquam Energy Systems
Grant Amount: $75,000
Status: Completed

Project Description:
This project researched the feasibility of adding small vapor compressors to solar-fired absorption chillers to lower the operating temperature of the primary generator, simplify the maintenance, and reduce the cost of solar-powered absorption heating, ventilation and air conditioning (HVAC) systems.

The nominal generator temperature in a single-effect absorption chiller is 190°F, and the coefficient of performance (COP) is between 0.7 and 0.8. Standard double-effect absorption chillers require the high temperature 1st stage generator to operate above 300°F. The nominal double-effect cycle COP is 1.2. Various modifications have been proposed to lower the generator temperature in absorption chillers. Any modifications must reduce the operating temperatures of the generators while maintaining the COP of the units. One proposal is to add a small vapor compressor to the basic cycle.

This project involved both the bench testing of an automotive turbocharger and the computer modeling of single effect (1E) and double effect (2E) compressor-assisted absorption chillers. The bench testing showed a turbocharger driven by steam at 240-250°F was able to provide the volumetric flow rate required by a compressor-assisted chiller. Additional work needs to be completed to develop mechanical compressors and/or thermocompressors that are optimized for this application.

The researcher developed computer models to simulate the effect of vapor compressors at selected locations in single and double effect lithium-bromide/water (LiBr/H2O) absorption chillers. Two locations for single-effect chillers and three locations for double-effect chillers were modeled. The best results were obtained for a double-effect chiller with the compressor located between the high temperature and the low temperature generators.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using small vapor compressors to reduce the cost, improve the performance, and simplify the maintenance of solar-powered absorption HVAC systems. The researchers established the following project objectives:

1. Develop computer models to simulate the operation and calculate the performance of solar-fired compressor assisted (SFCA) single-effect and double-effect absorption chillers with a $LiBr/H_2O$ solution as the working fluid.
2. Determine the location of the compressors that will provide the greatest increase in the temperature of the refrigerant in the cycle and thereby lower the required operating temperature of the generator.
3. Bench test a small compressor of the type that could be used in this application.

Actual Outcomes:

1. The researcher developed computer models to simulate the operation and calculate the performance of SFCA absorption chillers. The computer models determine all of the state

points of the $LiBr/H_2O$ solution in the cycle. The specified parameters are the temperatures of the chilled water and the cooling tower, the cooling capacity of the chiller, the concentration of the strong solution, and the compression ratio and compressor efficiency. The models calculate the properties at all of the state points and the coefficient of performance of the chillers and the flow requirements of the vapor compressors.

2. The project calculated results for two compressor locations for a single-effect chiller and three compressor locations for a double-effect chiller. For each compressor location results from the computer models show:
   a. The compression ratio and inlet volumetric flow rate.
   b. The outlet temperature and power requirement of the compressor.
   c. The operating temperature of and the heat input to the generator.
   d. The chiller COP.
3. The researcher bench tested a turbocharger from a 1990 Mazda 626, 2.2 liter engine. From those tests the researcher determined compression ratio, volumetric flow rate, power input, and isentropic efficiency of the compressor.

Conclusions:

1. The model performed adequately, although some cases of instability arose, particularly in "Task 7, Evaluation of the 2E Chiller" with the compressor located between the evaporator and the absorber. While the failure had little effect on this study, it creates doubts concerning the value of the model.
2. The calculations indicated the best location for a compressor in a 1E absorption chiller was between the generator and the condenser, though there was concern about the high volume flow requirements. The indicated best location of the compressor in a 2E absorption chiller was between the high temperature generator and the low temperature generator. In this case the high temperature generator can operate at less than 250^{o}F, with pressure just below one atmosphere. The compressor outlet temperature and volume flow rate are reasonable for a small compressor, and the overall COP is good. Any future work should focus on this case.
3. The bench tests of a small compressor emphasize the need for a systems engineering approach to the design of a compressor-assisted chiller. For example, the turbocharger was not the right device to use for this purpose. The researcher made no effort to address issues such as air leakage passed the turbine shaft. Rather, the bench testing simply recreated performance data known to the turbocharger manufacturer. A more useful result may have been obtained if the computer model had incorporated a parameterized model of the compressor. Then the researcher could have obtained ideal compressor parameters, allowing him to purchase a compressor built to those specifications.

Benefits to California:

Solar-absorption air conditioning is a renewable, non-polluting, environmentally friendly technology. It has the potential to displace conventional, electrically driven compression air conditioners, which is a major consumer of electricity statewide. The implementation of this technology has the potential to significantly reduce both the consumption of and the peak demand for electrical power. This will benefit all the residents of California.

Recommendations:

This project investigated the potential of using small vapor compressors in absorption chillers. The researcher identified the operating conditions of the Mazda turbocharger as similar to those useable in absorption chiller systems.

Additional research is necessary to optimize the design of mechanical compressors for solar cooling technology. Another approach is the use of thermocompressors to perform the required compression process. An R&D partner or a commercializing partner should be committed to this project before further public funds are committed.

The next steps are:

1. Identify and acquire a specific absorption chiller in which to incorporate a vapor compressor.
2. Perform a detailed specification of a vapor compressor that has the exact specifications required in this application using a trusted computer model.
3. Purchase a compressor optimized for absorption chillers that satisfies the specifications for performance.
4. Assemble and bench test the compressor-assisted absorption chiller.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

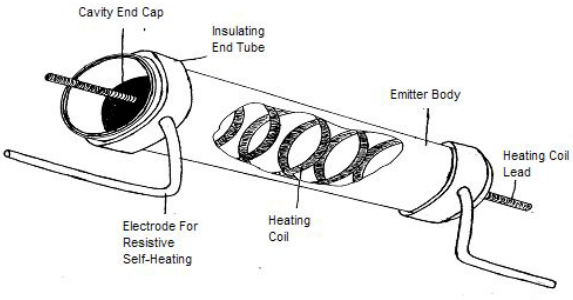
Spectrally Enhanced Incandescent Ceramic Incandescent Emitter

EISG Grant Number: 01-17
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Devon R. McIntosh (301) 283-6250
Organization: Sonsight Inc.
Grant Amount: $75,000
Status: Completed

Project Description:
Conventional tungsten-filament electric light bulbs are inefficient light sources. They radiate much more power in the infrared part of the spectrum than in the visible. While fluorescent lights are significantly more efficient and longer lived than tungsten lights, their performance has not yet attracted most residential consumers. In addition, fluorescent lights contain significant quantities of mercury, an environmental pollutant. There are other alternative light sources available to the consumer, which are more efficient than tungsten, but they have higher initial costs, and consumers consider them to be a poor spectral match to the solar visible spectrum.

This project proposes a new type of spectrally selective electric light emitter. It is designed to produce more visible light and much less infrared than an equivalent tungsten bulb and without the use of mercury. It would be potentially three times as efficient as tungsten-filament bulbs and significantly longer lived. Lighting accounts for about 19 percent of all U.S. electricity consumption and 9.4% of residential electricity consumption. In 1993 the majority of light bulbs in residential households were incandescent. According to the RECS Survey, 453 million lights out of a total of 523 million used one or more hours per day were incandescent (87 percent). California consumers could reduce their electrical consumption proportionally by replacing existing tungsten incandescent bulbs with a more efficient incandescent light. In 1999 discarded fluorescent bulbs contained 17 tons of mercury, of which 71% was deposited in the nation's landfills. While there is no consensus on the importance of mercury in landfills, its increasing concentration in the oceans and commercial fisheries is thought to endanger people's health, particularly the health of pregnant women and their offspring. Thus, California's environment would improve if another, more benign source of light replaced fluorescent lights containing mercury.

The key to the new light bulb is the development of a ceramic, spectrally-selective incandescent emitter that emits strongly in the visible spectrum from its surface when heated. The researcher proposed a millimeter scale emitter. The tubular emitter is made of doped zirconia powder, which has the characteristic of being an insulator at low temperatures and a conductor at high temperatures. This project proposed a new method of heating the emitter. In this method the tube is heated externally up to its conduction temperature using a radiant source. Then a current is passed through the tube causing resistance heating, bringing it to a higher operating temperature. The emitter material suppresses infrared emission from its interior through its microstructure, which is designed to consist of small grains interspersed with small voids. For the light source to succeed, its microstructure must be stable against the usual high-temperature grain growth at its operating temperature of 2,650 Kelvin (K) over a lifetime of several thousands of hours.



Proposed Outcomes:
The goal of this project was to determine the feasibility of using a new composite ceramic emitter design in incandescent bulbs to achieve a 300% increase in visible light per watt over standard incandescent bulbs. The researchers established the following project objectives:

1. Utilize a novel heating arrangement to attain a stable emitter temperature of 2,650 K.
2. Optically and physically structure the composite ceramic oxide emitter so that, when heated as designed, it emits three times more of its total radiated power within the visible spectrum than a standard 100 watt (W) incandescent bulb does.
3. Generate stability data supporting the long-term goal of achieving an emitter life of greater than 2,100 hours.
4. Obtain updated manufacturing estimates supporting a manufacturing cost goal of approximately $0.75 per bulb.

Actual Outcomes:
The research resulted in the following outcomes:

1. Utilize a novel heating arrangement to attain a stable emitter temperature of 2650 K.
   a. Radiant heating routinely achieved emitter turn-on.
   b. The thermally insulating emitter end tubes and molybdenum electrodes allowed emitter body temperatures of up to 2,653 K.
   c. The new electro-thermal stability model demonstrated that emitter (temperature) stability is insensitive to emitter dimensions and sensitive to incident radiation intensity.
   d. There is moderate quantitative agreement between the calculated and the measured minimum coil temperatures needed to prevent thermal runaway, but only qualitative agreement on the operating voltages.
2. Optically and physically structure the composite ceramic-oxide emitter so that, when heated as designed, it emits three times more of its total radiated power within the visible spectrum than a standard 100 W incandescent bulb does. Rapid grain growth in the first few minutes at high operating temperatures precluded measurement of spectral selectivity.
3. Generate stability data supporting the long-term goal of achieving an emitter life of greater than 2,100 hours. The researcher did not achieve this objective because rapid grain growth in the first few minutes of operation shortened emitter life. Therefore, no long-term testing was performed.
4. Obtain updated manufacturing estimates supporting a manufacturing cost goal of approximately $0.75 per bulb. The researcher did not meet this objective because of uncertainty about achieving adequate emitter life.

Conclusions:
The Program Administrator's conclusions from this project are:

1. Radiant heating can achieve emitter turn-on as a necessary step, though its outcome was not much in doubt, given the earlier experiments with heating by torch.
2. The molybdenum electrodes work as expected, a significant step since this new substance introduced a potential materials compatibility issue.
3. The new electro-thermal stability model validation does increase understanding of the method. However, the time spent on model development could possibly have been put to better use on more important unsolved issues of material stability.
4. The lack of quantitative agreement with the model is not a serious concern at this time.
5. Rapid grain growth at operating temperature is a serious concern.
6. Emitter lifetime of greater than 2,100 hours has not been demonstrated.

7. The manufacturing goal of $0.75 per bulb is uncertain at this time, due to the lack of a working design.

The goal of this project, to achieve a 300% increase in visible light per watt over standard incandescent bulbs through a new composite ceramic emitter design, remains unfulfilled. Although the project appears to have been well structured, in retrospect more emphasis could have been placed on issues of materials stability.

Benefits to California:
The primary benefit to the ratepayer from this research is a reduction in environmental impacts of the California electricity supply or transmission or distribution system. If this research were successful, it would lead to an incandescent light bulb that is three times more efficient than standard tungsten bulbs. Since 87% of the total of 523 million light bulbs used nationally one or more hours per day in residential households are incandescent, replacing them with a design three times more efficient would produce large savings.

The annual, national, average residential electricity consumption for lighting in 1993 was 940 kilowatt hours (kWh) per household. In the Western census region, the average household consumed 856 kWh of electricity for lighting at a yearly cost of $76 per household (1993 dollars). While these data are older than desired, and there is significant variation in the per unit cost of electricity within the Western census region, it is clear that California consumers could reduce their electrical consumption and expenditures significantly by replacing existing tungsten bulbs with a more efficient incandescent bulb.

Recommendations:
The researcher should examine the materials question of grain growth and lay out a plan, based on one or more new experimental results, before additional funding is considered. The Program Administrator suggests a program stressing more microstructural analysis of heated specimens and spectral measurements of them at high temperatures. Additional model development seems to be of secondary importance at this stage.

The Program Administrator also recommends some analysis of phase diagrams of the constituent pseudo-binary, ternary, quaternary oxide systems and carbon. A specific question in particular is whether initial heating may possibly cause transient liquid phases. If so, that could greatly increase grain growth, since diffusion constants in liquids can be orders of magnitude faster than in solids. If the *final* equilibrated composition does not contain liquid, then *transient* liquid phases might be avoided by optimization of initial time-temperature heating protocols.

Finally, thoria is thought to inhibit grain growth in tungsten and might prove valuable here (with suitable precautions of course). Industry has used it for many years, and its weak radioactivity might not be an environmental impediment. If thoria adequately inhibits grain growth, that result would at least demonstrate the feasibility of the program.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

SunGuard Roofing Tile for Natural Cooling

EISG Grant Number: 99-07
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Thomas Dinwoodie (510) 540-0550
Organization: Powerlight Corporation
Grant Amount: $74,885
Status: Completed

Project Description:
In hot climates where residential energy use is dominated by cooling needs, a cool roof can significantly reduce air conditioning costs. Most residential roofing systems have highly absorptive surfaces that conduct large amounts of heat into the attic space. Light colored roofing material has a positive effect on roof and attic temperatures. However there is no product on the market that offers both cool-roof benefits and photovoltaic (PV) electricity generation. Further, most PV systems are not aesthetically attractive when installed on sloped residential roofs. A need exists for an aesthetically pleasing, cool roofing product that supports PV integration.

In 1997, approximately 47% of all residences in the western United States had some form of air conditioning installed. Most new residences built in the hot interior valleys of California are equipped with central air conditioning. According to the California Energy Commission, air conditioning consumed ~8% of all residential electricity in1996. As more people move to hot inland areas the electricity used for residential cooling is increasing. Reducing the roof and attic temperatures can have a major effect of the amount of thermal energy that must be removed by the air conditioning system. Residential air conditioners often add to the peak demand in late afternoon when commercial and industrial demand also peaks. Reducing the roof and attic temperatures of residences in hot climates could lead to significant reductions in the electricity demand at peak hours.

The researcher in this project attempted to prove the feasibility of a new roofing material design that incorporates natural roof cooling, PV integration and aesthetic appeal. Natural cooling was achieved by providing two separate roof layers separated by an air layer. Proprietary supports maintained the separation. The researcher investigated materials for the top and bottom layer of the cooling channel as well as the use of a radiant barrier. Upon selection of the materials the researcher proposed building and testing prototype roofing material to demonstrate the cooling capabilities of the design. For building-integrated (new construction) applications, the researcher proposed a PV- and non-PV roofing tile to cover the entire roof. Non-PV roofing tiles were proposed to fill in areas where PV tiles would provide little electricity. Enhanced thermal benefits would be obtained over the entire roof area. The researcher intended to give the PV array an appearance of being integrated into the roof. The researcher anticipated that a similar design could be used in retrofit applications on existing buildings. This project included laboratory evaluation and field-testing of the building integrated product.

Proposed Outcomes:
The goal of this project was to prove the feasibility of a novel ventilated roofing tile incorporating a radiant barrier and proprietary supports that could be used with or without PV modules on residential roofs. The following project objectives were established:

1. Optimize the ventilated roofing tile geometry and materials to achieve a cost target of $2.50 per square foot (sf).
2. Determine life of ventilated roof material through accelerated life testing. Material should demonstrate the potential for 20-year life.
3. Reduce heat flow through the roofing material by 90%.

Actual Outcomes:

1. The researcher determined tile geometry through laboratory and field tests. The researcher selected materials for that prototype design. While tests indicated that most performance goals were met, the researcher did not meet cost targets. The researcher was not able to incorporate fully fire resistance materials within the price target.
2. The researcher installed a prototype 288 watt PV integrated module on an outdoor test roof at an independent laboratory. Thermal and electrical performance data were collected. The array consisted of 34 tiles, some with PV modules and some without. The researcher did not note any durability issues during the outside test period. Because the materials selected for the test articles would not be used in production, the researcher did not conduct accelerated life testing.
3. The researcher determined that heat flow through the ventilated roofing tile was reduced by 90% over the control material.

Conclusions:

1. Materials selected for initial prototypes will not meet cost goals. Further research is needed to identify materials that will meet all performance criteria including fire resistance within the cost target of $2.50/sf.
2. The Program Administrator recommends accelerated testing of ventilated roofing tiles once the researcher selects materials that meet the cost target.
3. The researcher successfully reduced heat transfer through the roofing material to the attic space. When PV modules are added to the ventilated roof tiles, total energy savings of 28%-35% could be achieved for typical residences in target markets. Target markets are new construction and retrofit (re-roofing) applications over existing asphalt shingle roofs, on buildings in hot, cooling-dominated climates. These climates include most hot, inland valleys of California. The building-integrated design should be designed and built as modular components to reduce installation costs. Significant engineering work remains to develop this product configuration.

The project final report was submitted with an extensive proprietary appendix. The published final report (Appendix A) does not include the information necessary to support the conclusions drawn. The reader is referred to the project researcher for access to any proprietary data.

Benefits to California:
While it is not ready for the market at this time, when it is fully developed and if project objectives are met, residential energy consumers will benefit from this product through lower energy bills and protection from system outages because of reduced peak loads. Small commercial and industrial buildings may be able to take advantage of this product depending on the architecture of the buildings. The electrical grid will be less congested and thus more stable. Additional environmental benefits derive from the renewable (PV) electricity that is generated in

the State. This additional electricity offsets electricity produced by conventional combustion electrical generators.

Recommendations:
The Program Administrator recommends continuing the product development once the researcher has developed possible schemes to meet product cost and performance goals. Suggested research steps include:

- Conduct further materials and tile geometry research to meet cost and performance goals.
- Perform accelerated life tests (mechanical, water resistance, fire and UV resistance).
- Determine potential energy savings when applied to houses in specific climate zones.
- Obtain commercially critical certifications (e.g. UL, ICBO).
- Develop distribution channels and partnerships with developers and roofing contractors.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Two-Phase Flow Turbine for Co-generation

EISG Grant Number: 99-33
PIER Area: Renewables
Principal Investigator: Gracio Fabris (818) 952-0217
Organization: FAS Engineering, Inc.
Grant Amount: $75,000
Status: Completed

Project Description:
There are many sources of boiling hot water currently not fully utilized for electricity production. These sources include geothermal, solar thermal, and bottoming cycles of large steam power plants. The energy in the heated water can be transferred to a thermodynamic working fluid to generate electrical power. Because the water is only under moderately high temperature and pressure, the working fluids often operate in the two-phase region (water and steam together, for example). Energy conversion devices that work in the two-phase region are typically low in efficiency and often suffer from poor durability. A possibility exists to greatly improve the overall cycle thermal efficiency. Impulse type two-phase turbines have moderate turbine efficiencies but a very high turbine blade erosion rate due to impingement by high velocity intermittent individual liquid droplets. While reaction turbines are more reliable than impulse turbines, the efficiencies of existing two-phase reaction turbines are poor. If the efficiency of two-phase reaction turbines can be increased to reasonable levels, then most of the advantages of two-phase cycles could be realized practically in many low energy conversion cycles.

The researcher's goal in this project was to show that a newly designed and patented turbine could operate at a turbine efficiency of at least 50%. For clarity, understand that because the best existing two-phase reaction turbine operates at 33%, the new turbine's efficiency will be a 50% relative improvement as well as an absolute efficiency of 50%. The researcher designed and tested improvements to the expansion nozzle of a two-phase turbine. To improve the turbine efficiency, the researcher proposed a proprietary nozzle design with a long spiral flow-path. The researcher analyzed the prior-art of two-phase reaction turbines and identified two major efficiency loss mechanisms. The first mechanism is the slip-loss induced by very large lateral separation forces. These very large forces separate liquid to one side of the nozzles and vapor to the other side. The force acting on the vapor and liquid at a given operating condition within the reaction turbine is constant. However, the mass of liquid per volume unit exceeds the mass of vapor. Therefore the accelerations of the liquid and the vapor are different and separation occurs. The second loss mechanism is the abruptness in flashing of liquid to vapor. In two-phase reaction turbines this effect is due to high over-pressurization (at pressures about 10 times higher than saturation pressure) and very short, inefficient nozzles. If these mechanisms could be eliminated, turbine efficiency would improve greatly.

Proposed Outcomes:
The goal of this project was to determine the feasibility of a two-phase flow turbine incorporating a curved reaction nozzle to provide at least 50% conversion efficiency.
The researcher established the following project objectives:

1. Build a 25 kilowatt (kW) prototype two-phase reaction turbine that operates at 20,000 rotations-per-minute (RPM).
2. Build a turbine test facility capable of heating water to 435^{o}F and 350 pounds per square inch gauge (psig), representative of the target applications, and configured for testing the two-phase turbine.
3. Test the prototype two-phase turbine, demonstrating efficiency of at least 50%.

Actual Outcomes:

1. The researcher completed design drawings and fabricated a 17-inch diameter turbine. The material yield stress point allowed operation up to approximately 50,000 RPM. The prototype turbine was operated several times at rotational speeds of 20,000 RPM, about 2.6 times higher RPM than prior two-phase reaction turbines.
2. The researcher constructed and instrumented a blow-down style test facility. This facility heated and stored 200 gallons of water at the required temperature and pressure (435^{o}F and 350 PSIG). Pressure, temperature, and flow meters were installed on the two-inch blow-down pipe feeding the turbine. Flow was controlled by a two-inch ball valve. Additional equipment included a three-phase generator chain driven by the turbine and coupled to three balanced and cooled load resistors. Typical laboratory instrumentation was installed.
3. The researcher conducted multiple test runs of the two-phase turbine. The results for eight runs indicate turbine efficiencies of 50.1% at turbine design speed.
4. An unexpected result was the challenge of maintaining the ball bearings in the turbine. The inner bearing race was mated to the hot input shaft while the outer race was attached to a much cooler structure. During the test runs the inner race heated and expanded, using up the tolerance of the stainless steel ball bearing. To avoid bearing seizure during test runs, the researcher used chromium steel bearings with wider tolerances. Some of the bearings still seized and the others rusted quickly, but satisfactory test runs were accomplished in the time available.

Conclusions:

1. The two-phase reaction turbine was successfully built to design. The complex curved flow path for the two-phase fluid required a numerical controlled machine tool driven by the design computer code to accurately implement the design. This is not a problem in a modern machine shop.
2. The blow-down test facility built as part of this project was adequate to obtain early development phase results. That facility allowed the researcher to obtain data sets for operational intervals of minutes. However, electric generator products are expected to run and generate power for intervals of 20,000 to 30,000 hours between overhauls. Long-term considerations, such as erosion of the turbine nozzle, were not addressed in this project.
3. The researcher reported (Appendix A) the prior art in reaction turbines was generated at Lawrence Livermore National Laboratory (LLNL). LLNL tested a reaction turbine that demonstrated efficiency of only 33%. The two-phase turbine tested in this project demonstrates higher efficiency than the LLNL turbine in almost all test cases. The approximately 50% turbine efficiency demonstrated in this project is a major improvement over the 33% efficiency of the prior art (See conclusion in #5 below). Larger reaction turbines may exhibit increased efficiency due to scale effects.
4. Bearing failure plagued this project. For future test rigs the researcher should retain a bearing expert with experience in high-speed turbo-machinery. Such an expert might recommend other bearing designs that do not rely on rolling elements.
5. The Program Administrator suggests caution in accepting the reported turbine efficiency. The approach used to measure the power generated and hence the efficiency of the two-phase reaction turbine under test may have yielded overly optimistic results. The turbine drove an electric generator and the electrical power was measured. The generator was chain driven. A transfer efficiency coefficient of 0.85 was assumed for the chain transfer, and a generator efficiency coefficient of 0.85 was assumed. While these may be reasonable engineering approximations, it is unfortunate the researcher did not measure

these coefficients. To understand the critical nature of these assumptions, consider the limiting case of perfect power transfer and generation. If the efficiency coefficients were both 1.0, the 50% efficiency reported would reduce to only 36%. That is still a 10% improvement over prior art. In fact, actual transfer efficiencies and generator efficiency are less than 1.0 resulting in a turbine efficiency of over 36%. Nonetheless, any potential industrial partner would want to have greater knowledge of the expected turbine efficiency and how it was measured.

Benefits to California:
Many sources of boiling hot thermal energy are available in California. These include geothermal, solar thermal facilities, and bottoming cycles of large power plants. Current recovery of these vast resources is hindered by lack of energy conversion devices that can operate efficiently while enduring the mechanical stresses of two-phase flow. If the turbine demonstrated in this project proves to be commercially viable, numerous new sources of energy could become available to produce electricity for California ratepayers.

This project did not perform a life cycle cost analysis. Thus it is not possible to determine the financial impact of this development to ratepayers.

Recommendations:
The results of this project support the feasibility statement for this project. A turbine efficiency of approximately 50% has been reported. The Program Administrator recommends calibrations of the researcher's test apparatus to more accurately determine this efficiency. Even in the range of 40 to 50% efficiency, this turbine is a major improvement over prior art. Rather than continue to develop improved turbine designs that operate at higher speeds, temperatures and pressures, the Program Administrator recommends the researcher reduce the design with proven feasibility to commercial practice. The Program Administrator recommends the researcher find a commercialization partner. With that partner the researcher should develop designs that have high reliability, durability, maintainability, and safety. In addition the researcher should perform a life cycle cost analysis to ascertain profitability of an energy cycle that includes the 50% efficient two-phase turbine.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

EISG Projects Completed in 2003

Biomass Boundary Layer Turbine Power System

EISG Grant Number: 00-06
PIER Area: Renewables
Principal Investigator: Darren Schmidt (701) 777-5120
Organization: EnergySchmidt
Grant Amount: $75,000
Status: Completed

Project Description:
This project explored the potential for cost effective electricity production from biomass in distributed generation applications. The focus was on the means of energy extraction from the high-energy flue gasses resulting from biomass combustion. Sufficiently energetic flue gasses from biomass combustion contain ash and other particulates that could hinder the operation of most high temperature machinery.

The researcher tested a turbine with a rotor that consists of many parallel disks. He measured its performance while firing biomass fuel. This turbine, called a "boundary layer turbine," relies on the friction of the gases passing through the rotor to impart motion to the shaft. The technology is well known for its resistance to erosion in viscous pumping applications.

The proposed turbine was not completed and made available in accordance with the project's schedule, however, a manufacturer, at no cost, supplied a low-efficiency turbine to the project. A used pressurized combustor was purchased and adapted to a pressurized combustion residence chamber. Over 40 hours of testing at various operating states was accomplished at very low research cost. At the conclusion of this test series, the researcher concluded that no significant barriers exist within the boundary layer turbine to hamper the use of biomass fuels.

Proposed Outcomes:
The goal of this project was to determine the feasibility of operating a boundary layer turbine on flue gasses of a biomass combustor. The following project objectives were established:

1. Demonstrate the performance of a boundary layer turbine operating on combustion flue gas.
2. Optimize turbine performance, achieve 21 % conversion efficiency.
3. Achieve low levels of deposition, corrosion, and erosion of the turbine.
4. Design the next generation boundary layer turbine.

Actual Outcomes:
Testing of a turbine proved that it did run on biomass fuel with the following performance.

1. Boundary layer turbine performance for five operational scenarios is tabulated here.

Case	Working fluid/fuel	Firing rate	Temper-ature	Pressure	RPM	Power	Isentropic efficiency
1	Compressed air	N/a	Unk	86 psig	8193	11.6 HP	Unk
2	Compressed air	N/a	69 ^{o}F	33 psig	1100	0.6 HP	16%
3	Natural gas flue gas	173,000 Btu/hr	832 ^{o}F	35 psig	6218	4.6 HP	12.25 %
4	Biomass flue gas	192,600 Btu/hr	737 ^{o}F	40 psig	6284	4.3 HP	11 %
5	Saturated Steam	Unk	N/a	100 psig	6500	12.4 HP	13.7 %

2. Conditions were varied to determine optimum turbine operating conditions. The highest efficiencies were obtained at the highest operating speeds. Under hot operating conditions (800°F) and less than 50 psig, efficiencies of 12% were obtained. The highest rotational speed under these conditions was 6500 rpm. The efficiency and horsepower curve are linear with speed, suggesting that higher efficiencies could be obtained. Increasing pressure increased power and efficiency. Increased temperatures had the same effect but to a lesser degree. The highest torques (100 in- lbs) were obtained at the lowest rotational speeds. The turbine was equipped with two nozzles. Primarily only one nozzle was used during testing. Experiments with the second nozzle resulted in little improvement in power or efficiency.
3. Qualitative assessment of deposition, erosion, and corrosion are as follows. 150 lbs of biomass was fired in the turbine with an average ash content of 1%. The biomass consisted of wood-derived sawdust and oats, fired separately. Firing of 100% biomass was achieved. Post inspection of the turbine rotor provided no indication of ash deposits, plugging between disks, or excessive build up in the turbine housing.
4. Evaluation of power cycles was completed to arrive at a design for the next generation biomass boundary layer turbine. This preliminary design is specified in the form of a process flow diagram.

Conclusions:

1. This project proved that it is feasible to drive a boundary layer turbine with flue gasses from biomass combustion.
2. The efficiency obtained was not as high as projected in the proposal, but the turbine used was not the one planned in the proposal. This was because when the time came to use it, the proposed turbine was not ready. Documentation of more efficient boundary layer turbines is provided. The conclusion is that higher efficiencies might be obtained with proper design of the turbine and the matching combustor.
3. No indication of ash deposits, plugging between disks, or excessive build up in the turbine housing was observed on posttest teardown. This is positive indication that this simple turbine architecture is tolerant of particulate matter in the working fluid. It seems obvious that partially burned pieces of biomass must not be fed into the turbine, but tolerance of fly ash can be a very useful characteristic.
4. Engineering calculations indicate that the achievable system efficiency may be as high as 25% with a boundary layer turbine. This will require an isentropic efficiency of 60% for the turbine. While this efficiency is theoretically achievable, only 49% efficiency has been achieved/reported in practice.

Benefits to California:

The benefits to California from this technology are derived from the simplicity of the system, and its potential to be transported to the source of the biomass. The challenge with forest slash and other forest biomass is its location. Transportation of the fuel to the power generator makes the fuel very expensive due to transportation costs. By transporting the power generator to the forest, the biomass fuel can be used to generate electricity. Then the problem is to transport the electricity to the consumer by attaching the generator to the grid. The added cost of grid interconnection equipment was not estimated in this project but could be high relative to the cost of the turbine.

Recommendations:
This project was proposed and funded with a targeted 21% isentropic efficiency. The efficiency achieved was 11% to 13%. The turbine efficiency must be approximately 50% or better in order for this technology to compete with established systems.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Catalytic Stabilizer for Industrial Gas Turbines

EISG Grant Number: 99-26
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Shah Etemad (203) 287-3700
Organization: Precision Combustion, Inc.
Grant Amount: $75,000
Status: Completed

Project Description:
Air emissions from combustion turbines used in mechanical and power generating applications are a major issue when seeking approval for installation. Oxides of nitrogen, NOX, are major constituents of those emissions. Gas turbine manufacturers have developed dry, low NOX (DLN) technology to reduce NOX emissions from over 200 parts per million to a range of 9 to 25 parts per million (ppm). These levels of emissions are achieved without the use of water or steam injection, or the use of selective catalytic reduction (SCR) devices in the exhaust. When SCR technology is combined with DLN technology the NOX emissions are reduced to the range of 2.5 to 5 ppm. This is the most common technology suite for large (>50MW) combustion turbines. Unfortunately SCR technology is very expensive making its use on the smaller combustion turbines uncommon. Smaller combustion turbines serve an important purpose in California's overall energy strategy when they are used in combined heat and power applications. In these installations over 70% of the energy of the fuel is put to productive use.

Researchers have determined the major reasons that DLN technology is limited to 9 ppm NOX. The primary reason is the use of a pilot burner to stabilize combustion over all operating conditions (i.e. startup, part load, full- load, and transients.) Without the pilot burner the engine could cease operation during various engine exercises. The pilot burner also reduces combustor "rumble", a vibration that can destroy an engine in a relatively short period of time. Although DLN pilots commonly burn only 2-5% of the fuel at full load, they are still the source of about 50% of the NOX emissions in a DLN burner. If the pilot burner emissions could be eliminated or reduced, a DLN burner could achieve NOX levels of less than 5 ppm.

This project tested the feasibility of using a catalytic stabilizer to replace the pilot burner in a regular DLN burner. The concept is to install the catalytic stabilizer in the fuel injectors (there may be 8 to 18 injectors in one DLN burner assembly). While catalytic combustion techniques have been under test for decades, those concepts replaced the entire DLN system with a catalytic system. The novelty of this concept is the use of catalytic technology only for the pilot burner, a small part of the overall combustion assembly. Full catalytic systems are large, often requiring extensive redesign of the engine casings. The catalytic stabilizer used in this project was built into an existing fuel injector without having to redesign major engine components. If this technology proves to be acceptable to the turbine manufacturers it could be readily retrofitted into combustion turbines already in the field. The use of the catalytic stabilizer could reduce DLN emissions to less than 5ppm NOX.

The catalytic reactor used in this study can begin and sustain operation at the relatively low outlet temperatures typical of today's combustion turbine compressors. That is the temperature of the air that after being compressed enters the combustion assembly. Operation of catalytic devices at such low temperatures (as low as 681^{o}F) is unusual and a key feature that makes this concept work.

Proposed Outcomes:
The goal of this project was to determine the feasibility of building a catalytic stabilizer in place of the pilot burner in a standard engine fuel injector. The following project objectives were established:

1. Design the catalytic stabilizer to fit into an existing fuel injector for a Taurus 70 engine (Solar Turbines Inc.).
2. Determine if the catalytic stabilizer can begin and sustain fuel injector operations at the relatively low temperatures of the engine compressor outlet air.
3. Achieve NOX emissions of less than 5 ppm for the Taurus fuel injector with the catalytic stabilizer replacing the standard pilot burner.
4. Determine if the catalytic stabilizer will allow leaner operation of the fuel injector.
5. Evaluate the operation of the catalytic stabilizer at a number of standard engine operating conditions.

Actual Outcomes:

1. The catalytic stabilizer fits into the existing Taurus 70 engine without major modification to the injector.
2. No pre-burner is required for the operation of the catalytic stabilizer. The catalytic stabilizer lit off at temperature around 355^{o}C (671^{o}F) during high pressure testing of the catalytic stabilizer – which is lower than the 435^{o}C combustor inlet temperature.
3. The integrated catalytic stabilizer and the Taurus 70-injector assembly delivered NOX and CO emissions below 5 ppm.
4. The catalytic stabilizer allowed leaner operation of the injector.
5. The catalytic stabilizer demonstrated variable-load operability. In addition, low emissions were obtained at both 100% and 50% load conditions.

Conclusions:
The catalytic stabilizer was built into two Taurus 70 production fuel injectors. The modified injectors were operated at both ambient conditions and simulated engine pressures. Data supported the key objectives of the program. The catalytic stabilizer could be designed to fit into the space envelope allowed by the Taurus 70 fuel injector. It did begin and sustain operation without the use of a pre-burner. And low emissions were achieved.

1. There are potential cost advantages to this technology since major modifications to the injector were not necessary.
2. The modified fuel injector could begin and sustain operation without a pre-burner. The tests showed that no pre-burner is required for the operation of the catalytic stabilizer from half load to base load conditions for the Taurus 70 fuel injector. It also operated free from auto-ignition and flashback over a wide range of stabilizer fuel-air ratios and airflows. Auto-ignition and flashback can be major operational problems with fuel injectors resulting in severe engine damage.
3. The project successfully demonstrated NOX and CO emissions of less than 5 ppm at Taurus 70 baseload (high pressure) conditions for a single injector.
4. The project demonstrated that leaner operation in the upstream end of the combustor can be achieved by the catalytic stabilizer. Additionally, the results show that the catalytic stabilized fuel injector can achieve low emissions at lower inlet temperatures than those required for a "conventional" catalytic combustor.

The project demonstrated that sufficient catalytic activity can be achieved by both baseload and half load conditions to achieve stable combustion.

After this project was completed the California Air Resources Board (CARB) lowered the limits on regulated emissions, including NOX. This project achieved the targets that were based on regulations existing at the time of the proposal, as well as satisfied the new regulations with the effective date of 2003. However, the PA is concerned that the approach of this project will not provide an adequate operational safety margin in the emissions levels to satisfy the newly imposed regulations with the effective date of 2007. While this approach may find a broad world market with huge reductions in emissions world wide, it does not appear to be applicable in California in its current configuration.

Benefits to California:
This project has contributed to the Public Interest Energy Research (PIER) program objectives for "Environmentally Preferred Advanced Generation" by advancing technology that will reduce emissions from combustion turbines typically deployed in mechanical and distributed power generation applications. Specific benefits are:

1. Improved air quality with cost savings. The catalytic stabilized fuel injector provides relatively low NOX levels at a low cost. Customers will ask the manufacturer of the gas turbine to guarantee air emissions. At this time the manufacturers have not indicated where they will guarantee an engine with catalytic stabilizers. If the guarantee level is below the level set by the California Air Resources Board for distributed generation, the catalytic stabilizer could be used throughout California to meet those regulations at reasonable costs.
2. Elimination of the use of ammonia to achieve low emissions. Ammonia is not used with the catalytic stabilizer. If gas turbine operators must install an SCR to meet low emission requirements, a measurable amount of ammonia would "slip" into the atmosphere.
3. Enhanced distributed generation. Californians will select gas turbine distributed generation more readily if the manufacturer can guarantee emission levels meeting the 2007 regulations. This will enhance the deployment of distributed generation and cogeneration within the state.
4. Improved air quality from retrofit. Manufacturers can apply the catalytic stabilizer technology to selected existing engines during an engine overhaul and upgrade without major modifications to the engine. These retrofits will further enhance the air quality of California.

Recommendations:
This grant proved the feasibility of replacing a pilot burner in a DLN combustor with a catalytic stabilizer. All tests were done with single injectors in test rigs. In subsequent research the development team should reconfigure the technology to satisfy the 2007 CARB emission regulations, install it into an actual engine and develop the control algorithms for engine operation. Engineers should measure emissions levels and compare them with the 2007 CARB regulations for distributed generation. Engineers should also determine reliability and lifetime of the catalytic stabilized device. The provider of the catalytic stabilized device and turbine manufacturer must determine the costs to manufacture and install these devices and compare those costs to the costs of competing technologies.
The PA determined that the data generated during the initial grant was sufficiently complete and successful to recommend taking this technology to the next step of development. To meet the 2007 CARB regulations the catalytic stabilizer would have to be reconfigured. Though significant, reconfiguration should not be a show stopper. Continued cooperation with a major gas turbine manufacturer will accelerate the transfer of the technology into the marketplace. This technology will be of the greatest benefit to engines of less than 50 MW.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Counter Rotating Wind Turbine System

EISG Grant Number: 00-09
PIER Area: Renewables
Principal Investigator: Kari Appa (949) 458-7314
Organization: Appa Technology Initiatives
Grant Amount: $74,915
Status: Completed

Project Description:
Most wind turbines in the world are single rotor systems, which provide simplicity, reliability and durability. Over the years, improvements have enhanced energy conversion efficiency of these single rotor systems. For example, blades have better aerodynamic characteristics, gears with reduced noise have better torque transmission efficiency, and alternators have better electrical efficiency. However, despite these improvements, single rotor systems are able to convert only a small fraction of the total wind stream energy into electrical energy.

Albert Betz predicted the maximum energy conversion efficiency of 59% when the axial wind speed is reduced by 2/3rd across a single rotor disc. However, practical wind turbines convert less than 40% of the wind energy into electrical energy. Hence, nearly 60% of the potential wind energy escapes without being harnessed. According to C. G. Curtis, the primary reason may be that a single rotor cannot be designed to achieve large changes in velocity or enthalpy. He therefore introduced the concept of velocity compounding using multiple rotors in tandem. This principle appears to be applicable to wind turbines as well.

This project investigated the power production and performance characteristics of a contra rotating wind turbine system.

Proposed Outcomes:
The goal of this project was to determine the feasibility of improving wind energy conversion efficiency by utilizing a contra rotating wind turbine system. The researcher established the following project objectives:

1. Investigate performance of a contra-rotating dual rotor system as a means of enhancing wind energy conversion efficiency, targeting reduction of energy costs ($/kWh) by 30%.
2. Develop designs for the contra-rotating dual rotor system for a low cost wind turbine ($/kW). The designs should allow early and economical transition to the utility scale wind turbines.

Actual Outcomes:

1. The project fabricated a prototype contra-rotating wind turbine system. The project team then installed the assembled unit on a 50- ft tower at the Oak Creek Energy Systems facility in Mojave, California. Tests conducted over a period of four months showed:
   a. At lower rotor speeds, energy extraction increased by up to 40% over an equivalent single rotor wind turbine.
   b. No detectable buffeting of the turbine blades occurred.
   c. Bending stress on the supporting tower was reduced by the contra rotating system over the single rotor system.
2. The study identified design solutions to the problem of transmitting the net torque generated by a contra-rotating turbine system to an existing electrical power-generating unit. Because these solutions make use of existing hardware, they depend on the

configuration of the existing equipment on the targeted wind farm. Two separate solutions are presented.

Conclusions:

1. The field tests demonstrated that power conversion efficiency could be increased up to 40% by using a wind turbine with a contra-rotating rotor system versus a wind turbine with only one rotor. This increase will result in increased energy generation from a given tower installation, but the researcher did not relate back to the reduced energy cost target.
2. Power conversion efficiency was high at low rotor speeds, suggesting applicability of contra rotating turbines to large utility scale wind turbines that rotate at 16-20 rpm.
3. Buffeting can be a fatal problem leading to premature failure of a wind turbine. It is encouraging that buffeting did not occur on the contra rotating rotor system.
4. The contra-rotating system reduces bending stress on the tower. This reduced bending stress results when the torques produced by two rotors counterbalance each other.
5. There is a good prospect for a utility scale contra rotating turbine system to produce from 30% to 50% more energy from high and low speed wind farms in California. This prospect needs confirmation through further testing.
6. If the prospect of extracting additional energy as suggested in item 5 above is confirmed, this technology should find a market in the retrofit of existing wind farms. The project identified two fundamentally different approaches:
    a. If the existing generator is provided with a dual winding (twin- generator) system, the same generator can be used for higher power rating. In this case, the shaft rotation power from the contra-rotating turbine is reversed in direction by a torque hub and combined with the existing turbine's power, both rotors driving the same generator.
    b. If the existing generator is not provided with a twin-generator system, a second generator and the contra-rotating turbine can be added in a back-to-back fashion to the rear of the existing generator. This may require a new mounting platform or simply brackets to attach to the existing platform.

Benefits to California:

Successful commercialization of contra-rotating wind turbine systems could reduce the cost of electricity to California ratepayers, promote increased power production, and stimulate business and employment opportunities in wind turbine industries within California. These benefits would occur by producing more wind-generated power per acre of land and by using common facilities such as support towers and possibly generators. At this time, wind- generated electricity is the most economical renewable energy. In California, wind energy production is highest in the afternoon to early evening time period. This is also the time that demand for electricity peaks in California. Currently these demand peaks are met with relatively costly simple-cycle combustion turbines. Increasing wind power production would offset the need to run these "back- up" turbines. Air quality would also improve since simple cycle combustion turbines have relatively high emissions of NOX and CO.

Recommendations:

The present study demonstrated the feasibility of a contra-rotating wind turbine system by using readily available components. The next step is to design, build and test a utility scale, grid connected wind turbine system. A major task in the next steps is to assess cost effectiveness of the counter-rotating design.

The suggested next steps are as follows:

1. Select a grid-connected environment in the 50 to 100 kW power rating range.
2. Design and build the units to a cost target.
3. Team with a wind power production company to install one or more units.
4. Conduct power production performance studies with grid-connected power loading for a period of one year or more.
5. Assess the cost-effectiveness of dual rotor system versus the single rotor system using available data.
6. After successful completion of this study, plan to transition the technology by licensing to manufacturers or utility providers.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Dev/Char of Improved Dye-Sensitized Nanocrystalline Solar Cells

EISG Grant Number: 99-10
PIER Area: Renewables
Principal Investigator: Jin Zhang (831) 459-3776
Organization: University of California, Santa Cruz
Grant Amount: $75,000
Status: Completed

Project Description:
A research group at the Swiss Federal Institute of Technology in Lausanne, Switzerland has developed a potentially low cost solar cell based on "sensitized" organic dyes and titanium dioxide, (TiO_2, a material used in white paint). The Swiss technology has an experimentally determined, overall sunlight to electrical energy conversion efficiency of 7 -10 % under direct and diffuse sunlight. While this conversion efficiency is lower than the approximate 15 % of commercially available solar cell technology, the solar cell based on organic dyes and titanium dioxide offers advantages including environmentally friendly components, low temperature processing, and potentially lower costs to consumers. Calculations indicate that solar cells of at least 10 % efficiency could be realized at less than $3 per Watt cost using the proposed technology. This may be competitive with conventional electricity generation in selected applications, and the approach could open up new markets in flexible solar cells used for consumer applications such as computers and cell phones, as well as in grid-connected distributed power generation. These markets are already over 100 Megawatts per year at a cost of approximately $6 per watt. Patents for the new technology have been issued. To reach new markets the researchers may need to file additional claims for intellectual property protection.

Liquid electrolytes are volatile. Solar cells produced with liquid electrolytes suffer from reduced reliability and lifetime. The purpose of this project was to prove the feasibility of a method to reduce these technical shortcomings. While the existing state of the art of the new technology holds the promise to reduce costs for solar generated electricity, the reduced reliability due to the volatile liquids limits potential application of this technology. This project involved replacing the liquid electrolyte with suitable solids.

The researcher chose conductive polymers as the replacement for the liquid, specifically, polythiophenes.

Proposed Outcomes:
The goal of this project was to determine the feasibility of replacing the volatile liquid in the dye sensitized nano-crystalline solar cell with conductive polymers. The following project objectives were established:

1. Determine if charge transfer can occur via the polythiophenes, and whether this material itself absorbs light.
2. If polythiophene does absorb light, determine if that absorption interferes and competes with light absorption by the dyes used in the state of the art device, and whether it can replace these dyes.
3. Measure the charge carrier dynamics of the dye, polymer, and TiO_2 suitable for this application. Construct an energy band diagram to better understand the functioning of solar cell with conductive polymers, and to optimize the solar cell output. Select an appropriate material based on these data.

4. Synthesize nano-crystalline TiO 2 films.
5. Fabricate, test and optimize solar cells using the materials exhibiting the best properties.

Actual Outcomes:
The following outcomes were achieved:

1. The researcher determined that polythiophenes could transfer charge and selected a hole-conducting polythiophene polymer. The researcher performed extensive tests on the absorption of light by the polythiophene and found that some polythiophenes can be both light absorbers and charge transporters.
2. One polymer, P3UBT, can act as a dye and a hole conductor possibly eliminating the need for a separate dye. This approach suffers from low mobility of charge carriers in the organic layer leading to low solar conversion efficiencies. For that reason, the grantee suggested using a separate dye and a separate transparent version of the polythiophene polymers along with porous TiO2 in future work. A transparent polythiophene polymer will not interfere with light absorption by the dye.
3. This project measured charge carrier characteristics, constructed energy band diagrams and developed techniques to characterize materials suitable for the dye based solar cell. While specific polymer and dye combinations are recommended as a result of this work, the researcher recommends future work that will focus on materials with higher surface areas and therefore higher photocurrents.
4. The project synthesized TiO 2 films using sol gel depositing technique.
5. The researchers fabricated solar cells using sol gel deposited TiO 2 and the above polymer. They tested solar cell devices, and found that the junction properties are unique as well as efficient for the geometry selected. However the cells they created were single layer cells with an efficiency of only 0.032%. The grantee estimated that with 200 layers like the one reported, a solar cell with a solid electrolyte could be over 6% efficient. No further optimization work was reported.

Conclusions:
The researcher utilized TiO 2 materials, together with solid polymers to fabricate solid-state solar cells. These devices produced encouraging results given the fact that only a thin layer of polymer and a single layer of TiO 2 were utilized. Current voltage characteristics of devices fabricated using this technique are consistent with the energetics of the components, and are encouraging when compared to existing technology based on sensitization mentioned above. The researcher obtained expected results from a single layer of sensitizer (polymer), and a flat TiO 2 surface given the energy band diagram, and spectroscopic characterization. With the techniques and materials developed in this project, the researcher measured voltages over 0.8 V and current densities of 100 micro-amps per square centimeter of active area with one sun of illumination. These results, reported for the model system, are not related to performance needed in a commercial device. There is no indication in the final report of the magnitude of improvement needed for commercial success.

The goal of this project was to determine the feasibility of replacing the volatile liquid in the dye sensitized nano-crystalline solar cell with conductive polymers. Based on results, commercial feasibility may be possible if the emphasis is now placed on utilizing porous or multi- layer materials. The most critical issue for future work will be the extension to higher surface area materials that can result in higher photocurrents. Specific performance criteria should be established before subsequent work is begun.

Benefits to California:
At this point in the research, potential benefits to California can only be qualitatively estimated. The experimental results support the feasibility of replacing the liquid electrolyte with a conductive polymer. The long-term benefits to California ratepayers include lower cost solar cells. The cost of future cells produced with this technology is difficult to determine at this time. However, if the lower cost ($3 per watt) is achieved, more ratepayers will install grid-connected solar power generators. These installations will help to diversify the California fuel portfolio. Increased utilization of solar energy to replace peaking power plants will greatly reduce the levels of CO2 and NO_x in the atmosphere.

There are other solar cell technologies that promise similar benefits. Sharp Corporation recently announced a new solar cell that employs organic pigments to change light into electricity. Sharp succeeded in switching the necessary electrolyte in the organic solar cell from the liquid state to a solid-state material. Sharp estimates that this new innovation will cut the cost of solar cells by one half. Sharp did not report an absolute cost or price.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Direct Operation of Solid Oxide Fuel Cells on Natural Gas

EISG Grant Number: 99-30
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Scott Barnett (847) 491-2447
Organization: Northwestern University
Grant Amount: $74,958
Status: Completed

Project Description:
This research project targeted the generation of electricity using fuel cells with pipeline quality natural gas. A combination of factors – low noise, high efficiency, ultra- low emissions, and the ability to utilize readily-available natural gas – make fuel cells a generally desirable generation method.

Most fuel cell systems consume hydrogen derived from natural gas using some form of fuel processor. However, the fuel processor adds considerable complication and expense to fuel cell systems, exacerbating the problem of bringing costs down to competitive levels, especially for smaller plants. Until recently, it has not been thought possible to operate fuel cells directly on hydrocarbons. Recently low-temperature solid-oxide fuel cells (SOFC) have operated directly on methane. This demonstration signals an important new opportunity for making simple, cost effective fuel cells. Fuel cell operation on pipeline natural gas is considerably more difficult than operation on pure methane because pipeline gas contains higher hydrocarbons. This project developed a fundamentally new type of fuel cell anode with a specific anode composition. This anode was successfully tested on propane, a higher hydrocarbon constituent of natural gas.

Proposed Outcomes:
The goal of this project was to determine the feasibility of anodic fuel conversion for a SOFC operating directly on natural gas. The key innovation was to develop the anode composition that satisfied the requirements for fuel cell operation. Subsequently the researcher verified that the higher hydrocarbons present in natural gas could be electrochemically oxidized without carbon deposition at the fuel cell anode. The following project objectives were established:

1. Develop multiple SOFC anodes based on Ceria with reduced Ni content and Ru-Ceria. During the project a third composition using a conductive ceramic was added.
2. Eliminate carbon coking on the anode when the SOFC is operating on propane. Characterize each anode performance by scanning electron microscopy for detection of carbon on the anodes, impedance spectroscopy, and fuel-cell current-voltage measurements.
3. Verify anode performance in a fuel cell stack. Select the most promising anode compositions for natural gas operation. Incorporate the selected anodes into fuel cells and test as a function of fuel composition and temperature.

Actual Outcomes:

1. Ceria-based anodes with reduced Ni content, Ru-Ceria anodes, and anodes using a conductive ceramic with greatly reduced Ni were constructed. These anodes were evaluated and found to exhibit the required physical characteristics of porosity and conductivity. The conductive ceramic anode reduced the function of the metallic component to that of a pure catalyst. This allowed the researcher to make a major reduction in the amount of noble metal in the catalyst.

2. The anodes were characterized. Impedance spectra were found to be acceptable. Coking on the anodes was evaluated. Results showed that Ru and Ni provide similar electrochemical performance. Less coking was found on the anodes with reduced metal fraction. However, at very low metal content there is insufficient conductivity in the anode. From these data the research developed the innovation of replacing the metal with a conductive ceramic. This is a key outcome of this project. The innovative anode is composed of three materials, an electronically conducting ceramic, ionically conducting ceramic, and a metallic catalyst. It is highly resistant to coking.
3. Ceria-based anodes with reduced Ni content (Ni-GDC) and the ceramic Ni anodes were chosen for fuel cell testing. Initial performance using hydrogen fuel and air indicated only small differences between the two anode compositions. All subsequent testing focused on the ceramic Ni anodes. Performance using methane and air was found to be similar to known performance of prior methane fuel cells. When operating on propane fuel and air the ceramic Ni anode demonstrated improved performance when compared with the Ni-GDC anodes. Further, after several hours of operation at peak power the ceramic Ni anodes were free of coking while the Ni-GDC anodes showed heavy carbon deposition (gram quantities).

Conclusions:

1. This project has verified the feasibility of operating solid-oxide fuel cells (SOFC) directly on pipeline quality natural gas. In California the gas is composed of methane and higher hydrocarbons with controlled amounts of sulfur in the form of Mercaptans, an odiferous sulfur compound deliberately added as required by law for safety purposes. It is expected that these Mercaptans would be removed from the fuel fed to any operational fuel cell to avoid poisoning of the metallic catalyst. Removal techniques include use of activated carbon filters, zinc oxide or zinc acetate.
2. This project tested SOFC performance on higher-hydrocarbon components of natural gas, and showed that the fuel cells can be operated with propane.
3. After testing Ni-Ceria and Ru-Ceria anodes, the researcher determined that anodes with very low Ni content, using a ceramic conductor to provide anode conductivity, yield good performance. That is, they provide fast electrochemical oxidation, and hence high power densities, without carbon deposition.
4. This researcher utilized two ceramic constituents with an embedded metallic catalyst in his design approach. Because the relative amounts and the chemical nature of each of the three constituents can be altered to match a specific fuel or operating condition, a designer has great flexibility for improving fuel cell performance.
5. A major advantage of the new anodes is that they can be cyclically reduced and oxidized without degrading performance. This redox cycling is expected to occur regularly on periodic shutdown of small generators when the fuel flow is stopped. Thus, the new SOFC anodes may enable new applications of SOFCs that rely on the direct use of high energy density hydrocarbon fuels or feature frequent on-off cycling (e.g. portable power, auxiliary power units, and distributed generation.) While early stability tests of these anodes are promising, longer-term tests are needed.

Benefits to California:

The PA's assessment is that the benefits to be derived by the California electric ratepayer from the continuation and successful conclusion of this line of research accrue in the area of distributed generation. Distributed generation benefits directly by the availability of a quiet, low emission, cost effective power source using a readily available fuel. By operating on both natural gas and propane, these fuel cells can be configured as uninterruptible power sources for the communities they serve. By operating at an estimated thermal efficiency of from 40% to 60%, these fuel cells

reduce the amount of carbon dioxide produced per unit of electricity, thereby reducing the detrimental effect from this assumed greenhouse gas. By providing high grade heat, ~700 oC as a byproduct, the overall fuel efficiency of the distributed generation network can be improved substantially by situating the generator facilities as combined heat and power installations. Such a configuration is feasible given the quiet, non-polluting nature of fuel cells.

Recommendations:
In order to advance this technology towards commercialization, R&D efforts must be carried out to improve and optimize the structure and composition of the new ceramic anodes for use with natural gas. This research should investigate and determine the following:

1. The effects of sulfur-containing compounds should be assessed, in order to determine whether a sulfur cleanup step will be required for the SOFC generators using these new anodes. If filtering of the gas is required, used filters should be evaluated for toxicity and their proper disposal should be considered.
2. The long-term behavior of SOFC fuel cells incorporating these anodes must be assessed.
3. The anode development work should include the criteria that the anodes achieve stable long-term performance.
4. The long-term test should include frequent cycling of operating conditions, including exposure to air, as expected in the real operation of small SOFC generators.
5. Finally, the anodes should be used as the support element of thin-electrolyte SOFCs. This will not only provide the best overall performance, but it matches the SOFC configuration being commercially developed.

This research effort should be undertaken in tandem with a commercializing partner. If these anodes can be incorporated into the existing SOFC configuration of commercial interest, it will maximize the commercial prospects for this new anode technology.

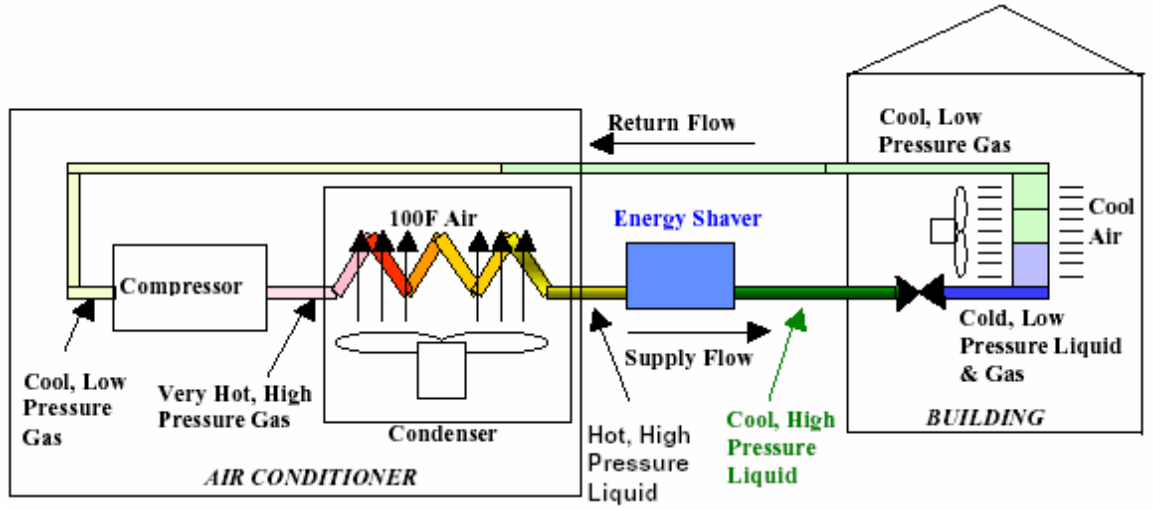
Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Energy Shaver-Thermal Energy Storage Device for Air Conditioner

EISG Grant Number: 99-16
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: James Lester (970) 963-2517
Organization: Redstone Engineering
Grant Amount: $74,695
Status: Completed

Project Description:
This project researched the feasibility of using a thermal energy storage device based on a salt hydrate to improve the performance of vapor-compression air conditioners of less than 5 tons capacity. A device using a salt hydrate to provide a relatively cool heat sink for the air conditioner working fluid during the hot part of the day was investigated. The stored heat is rejected from the salt hydrate to cooler night air to complete the cycle. With this device, an air conditioner can be up to 30% more efficient on very hot days. The schematic shown illustrates this system.



Thermal energy storage systems that use salt hydrates have been used for many years in solar heating systems. The innovation in this project is the use of salt hydrates for energy storage on the hot side of a vapor compression air conditioner.

Proposed Outcomes:
The goal of this project was to prove the feasibility of using a salt hydrate energy storage device to improve the efficiency of existing vapor-compression air conditioners. The researcher established the following objectives:

1. Perform preliminary modeling of the air-conditioner/energy storage system.
2. Model the salt hydrate containers.
3. Select the energy storage system materials.
4. Model and bench test the heat exchanger and related components.
5. Perform final modeling of the energy storage system.

Actual Outcomes:

1. The researcher wrote a FORTRAN computer program to model air-conditioning systems of 5 tons or less. This model used the FORTRAN-compatible Gaspak^{tm} fluid properties program package to calculate refrigerant properties. A reciprocating compressor for the model was chosen. Future researchers must modify the model to incorporate the more

common scroll compressors. The project exercised the model for numerous sets of conditions.

2. This project found that an acceptable salt hydrate container is one that meets the heat transfer requirements with a pressure loss and airflow that can be obtained from a low cost fan. The surface area required for heat transfer for a 5-ton unit is 6306 in2. The project analyzed several container wall geometries for the heat exchange surfaces. The baseline configuration is a cylindrical annulus 48 inches high, 17.5 / 20.5 inches inside/outside diameter, and having pleated surfaces.
3. The researcher, through review of literature, identified several useful hydrates: calcium chloride hexahydrate, sodium sulfate decahydrate, disodium phosphate dodecahydrate, and mixtures of sulfate and phosphate hydrates. These hydrates are compounds of salts and water in which the water bonds to the salt molecules when the temperature drops below the freezing point of the hydrate. This gives the hydrate a large latent heat of fusion that is released when the water/salt solution freezes. The selected mixture was 5/35/60% phosphate/sulfate/ water with 3% borax additive.
4. The researcher substituted water for Freon^{tm} in the system bench test. Tube spacing, container wall spacing and the hydrate were the same as in the planned, full-size energy storage device. For the heat flux per degree of temperature difference to be the same for the full-size energy storage device and the bench-test energy storage device, a scaling factor was calculated. Using this scaling factor the researcher built a bench-test heat exchanger tube six feet long to maintain equivalent heat transfer.
5. The project iteratively updated the model of the energy storage device and incrementally improved it during the project bench test. The researcher incorporated the results of the tests as well as the empirically determined heat transfer coefficient in the model.

Conclusions:

The project results indicate the technology is feasible and the salt hydrate energy storage device could provide measurable benefit when installed in an existing system. On a new or replacement system, the user would see immediate cost savings from reduced demand charges and energy consumption. The researcher suggests new replacement air conditioners equipped with the salt hydrate energy storage device could be smaller, therefore, they could cost the same as or less than the larger units they replace. This would offer an immediate payback.

1. The system modeling produced the following conclusions:
   - Project results indicate a demand reduction of 25% and an energy savings of 23% are possible when a 3-ton air conditioner augmented with the energy storage device replaces a 4- ton air conditioner. (The researcher made an unwritten assumption that comfort levels would be equivalent.) Energy savings are negligible for a simple retrofit into an existing air conditioning unit.
   - Retrofit applications require modifications to the air conditioner evaporator to realize maximum benefits.
   - The energy storage device is best suited to applications where dehumidification is usually required.
   - The melt/freeze cycle operates with normal ambient conditions.
2. Data from the salt hydrate modeling and testing led to the following conclusions:
   - A nucleating agent is required to stabilize the refreeze temperature.
   - Some salt settling occurs with the selected mixture, resulting in a loss of thermal capacity of about 5%. Mixing or some other measure is needed to maintain long-term thermal performance. Additional energy is required for the mixing operation.
3. The researcher identified and used effective combinations of known salts for the energy storage device.

4. Bench tests led to the following conclusions:
   - The scaled version of the Freon[tm]-to-salt heat exchanger design did not perform as well as expected. The outlet temperature rose 22°F by the end of the test when the model predicted a rise of 18°F.
   - Although the performance is adequate, additional heat transfer area (longer tubes or extended surfaces) is necessary to meet the stated heat transfer requirements.
5. The project produced data that has been incorporated into a model of the system. Future researchers in this field can use these data and the updated model.

Benefits to California:
Electric power demand exceeds supply during hot summer days in many areas of the state. A large percentage of peak power demand is driven by air conditioning demand. Expanding new house construction in hot areas of the state is magnifying the problem. Almost all of these houses are equipped with air conditioning.

The salt hydrate energy storage device tested in this project would have a measurable impact on the California's energy consumption if it were widely implemented in new and replacement applications. Negligible benefits were found for simple retrofit. A significant portion of California has weather suitable for using this thermal storage device.

Recommendations:
Two major areas requiring further development are mixing of the salt hydrate to ensure repeatable, long-term performance and product packaging to integrate the salt hydrate energy storage device with new or existing air conditioning equipment. Salt based energy storage systems, while offering great advantages to energy storage, have problems of heat transfer, settling, corrosion, and often cost. The PA recommends research work on these problems. Once solutions are found, the researcher should team with a manufacturer of air conditioning equipment to test a prototype energy storage system for energy performance and user comfort.

Progress Made Subsequent to the Initial Report:
The Energy Shaver is now called the Therma-Stor Cooling Booster (TCB).

The TCB has been developed and refined over the last four years. Each iteration resolved technical challenges and improved the design. Two major technical challenges that have been resolved are effective heat exchange with and long-term performance of the salt hydrate. The TCB is now in the I&I Category 2, Stage 3 Development stage.

A residential field test in the summers of 2001 and 2002 in Boulder, Colorado proved that the TCB increases efficiency and cooling capacity. In the test, a two year old 10 SEER 4-ton air conditioner was replaced with a new 10 SEER 3-ton air conditioner incorporating the Therma-Stor Cooling Booster. The extra cooling provided by the TCB enabled the 3-ton unit to cool the 2450 square foot residence to a low of 73°F with an outdoor temperature of 95°F. This was two degrees warmer than the 4-ton unit could achieve. The cooling demand, however, was easily met when the thermostat was set at 75°F. Energy measurements showed electric current demand dropped from 19.5 amps to 14.5 amps at 230 VAC, thus reducing peak demand by 1.15 kW. The TCB boosted the cooling well into the evening, at which time extra cooling was no longer needed. The fan consumed approximately 1.5 kWh each night to reject heat from the TCB and prepare it for the next day. Figure 1-2 shows the 4-ton unit and the 3-ton unit with the TCB. Figure 1-3 shows test data of the 3-ton unit with and without the TCB. Note that when the TCB is on, the Freon temperature at the TCB outlet (blue line) is much lower than when the TCB is off. This colder Freon produces more cooling at the expansion valve and evaporator in the house.

Although this test successfully replaced a 4-ton unit with a 3-ton unit, the proposed program will take a more conservative approach. New units having ½ ton less rated cooling capacity than those typically required will be installed.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Energy-Efficient Air-Handling Controls

EISG Grant Number: 00-12
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Clifford Federspiel (510) 418-3392
Organization: Federspiel Controls
Grant Amount: $75,000
Status: Completed

Project Description:
A large fraction, in some cases as much as 24%, of the energy consumed in buildings is used to operate fans that move air for heating, ventilating, and air-conditioning (HVAC). Much of the fan energy is wasted because fans are not operated in the most efficient manner. Inefficient fan operation can increase cooling energy consumption as well as fan energy consumption when their operation causes more air to be cooled than is necessary. Furthermore, inefficient operation of HVAC fans increases grid peak demand when electricity demand is high.

If fans could be operated efficiently, moving only the air needed, when it is needed, then savings would accrue in two areas. First, the fans would operate for less time, reducing their energy consumption by 20 to 40% and second, less fan operation means reducing the mass of air that requires cooling. This excessive or wasted cooling energy is estimated to be 10% of the total.

The researcher in this project proposed to develop new, more energy efficient strategies for operating air- handling equipment. To quantify the potential savings of these strategies the researcher embedded them into an analytical model. The model predicts the transient response of pressures, velocities, and temperatures in the system and uses sequential modes of operation to approach the set point. Actual data from a large office building in Oakland, California, were used to calibrate the model. The researcher developed a new model based on two strategies. The first strategy, called "Efficient Air-handling StrategY" (EASY), is a system control that can be implemented with a finite state machine in which states are modes of operation such as "economizer enabled" or "economizer disabled." The second strategy, called "Static Adjustment based on Volume flow" (SAV), employs resetting static pressure based on supply airflow rate. SAV can be implemented as part of EASY or as a standalone strategy. The researcher tested both strategies and found the majority of the benefits derived from SAV.

Project Objectives
The goal of this project was to determine the feasibility of using an intelligent ventilation fan controller to reduce the energy consumption of the fan by more than 20%. The specific objectives of the project were as follows:

1. Develop, using optimization and computer simulation methods, a new energy-efficient algorithm to control air-handling equipment in buildings.
2. Reduce fan energy consumption by 20%-40%.
3. Reduce cooling energy consumption by 10%.
4. Demonstrate stable operation of the fan controls while minimum ventilation, appropriate building pressurization, and appropriate temperature control are maintained at all times.

Project Outcomes:

1. The researcher used an existing model of air-handling systems for a starting point. The researcher calibrated the model using data from the Elihu Harris State Office Building in Oakland, California. The researcher determined optimal system behavior and then

identified patterns of behavior that could be encoded as control rules. The rules were designed to achieve nearly optimal performance.

2. The researcher expected reductions in energy consumption from reduction of throttling losses at the control dampers (exhaust, return, and outdoor air dampers) of the air-handling unit. The researcher reported fan energy savings of 26.3% over the base case. However, the researcher chose a system with no static pressure reset as his base case. There are existing control schemes that use static pressure reset that are reputed to perform as well as or better than EASY with SAV. When compared with state-of-the-art systems the strategies developed in this project may or may not have a comparative advantage.
3. The researcher expected gains in cooling energy to arise from better control over outdoor airflow rates. Existing systems using fixed minimum damper positions for regulating outdoor airflow can over-ventilate when it is hot, increasing cooling energy consumption. The project strategy directly controls outdoor airflow rate. Cooling energy savings were reported to be 17.4%. Again, the researcher compared his results to a base case with no static pressure reset. The comparative advantage to state-of-the-art systems may be considerably less.
4. The researcher invented a simpler way to model the behavior of fans. The researcher could not get the optimizer code to converge to the best operating point. Instead, he used trial and error methods combined with knowledge of existing strategies incorporating his findings into the EASY code. With these modifications, the models were stable and met minimum HVAC conditions required for a building. The researcher reported a faster system response time for his control system.

Conclusions:

The feasibility of the intelligent fan control strategy was proven.

1. The control strategies developed in this project cause a fan system to use less energy than the base case while ensuring that control requirements are met at all times.
2. The control strategies can reduce fan energy consumption by a much as 26.3% when compared to a system without static pressure reset.
3. The control strategies can reduce cooling energy consumption by as much as17.4% when compared to a system without static pressure reset.
4. The control strategies appear to be easier to tune than existing strategies. They exhibit faster response time when tuned properly. System settling time was reduced to 30 minutes from two hours.
5. The researcher should clearly establish the technology baseline against which he is calculating his energy savings calculations. His should compare to the best available technology.

Benefits to California:

The project demonstrated the proposed control strategies could reduce average power by 0.23 W/ft2/year in buildings with variable air volume (VAV) air-handling units. This is a large potential reduction in energy consumption. The researcher's calculation is based on the premise that static pressure reset is neither widely employed nor available. Based on data from DOE, the researcher estimated the proposed control strategies, if implemented in all applicable buildings, would reduce energy costs by $928 million/year nationwide and $171million/year in California. Primary beneficiaries would be the owners and/or operators of large air-handling systems incorporating variable air valve technology. Other ratepayers would benefit from the decreased load on the grid during peak demand periods.

Recommendations:
The researcher is encouraged to survey manufacturers of controls for VAV systems to determine what is commercially available. Energy savings calculations should be based on the best available technology rather than the most commonly deployed. Alternately the researcher could find his concept provides large energy savings at costs significantly lower than the best technology available today. If that market study confirms a large energy savings potential, then a field test is recommended to quantify and validate the energy efficiency benefits in a large building. The tests should be conducted during the summer so cooling energy benefits and fan energy benefits can be quantified. A widely accepted test procedure should be followed to establish credible data. Methods for commissioning SAV to produce the largest energy benefits could also be investigated.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Completed.

Increasing Efficiency of Geothermal Energy Generation with High Resolution Seismic Imaging

EISG Grant Number: 00-10
PIER Area: Renewables
Principal Investigator: Dimitri Bevc (650) 969-3886
Organization: 3DGeo Development, Inc.
Grant Amount: $75,000
Status: Completed

Project Description:
This project targeted an important energy source in California, geothermal energy. The researched seismic imaging technology has the potential to reduce the cost and risk associated with exploration and development of geothermal resources. This technology may lead to increased utilization of California's extensive geothermal resources, which provide an environmentally sound alternative to fossil fuels.

High-resolution reflection seismic imaging has been very successful in oil and gas exploration. It is the number one pre-drilling risk reduction technology and is applied on a routine basis to oil and gas exploration and production projects. Seismic technology has substantially reduced exploration cost, exploration risk, and environmental impacts. Despite its promise, reflection seismic imaging has not been applied extensively or with great success to geothermal exploration.

This project has applied existing, tested, oil and gas exploration algorithms to geothermal field seismic imaging data. The results demonstrated the potential utility of high-resolution reflection seismic imaging applied to geothermal objectives. They represent an improvement over previous research results and demonstrate that application of state-of-the-art seismic imaging technology and methodology may be beneficial in geothermal applications.

Proposed Objectives:
The goal of this project was to determine the feasibility of applying high-resolution reflection seismic imaging in the geothermal environment to map geothermal reservoir zones. The researcher established the following project objectives:

1. Modify imaging algorithms for application to the seismic imaging data acquired at the Coso geothermal field.
2. Preprocess reflection seismic data acquired at the Coso geothermal field.
3. Generate a high-resolution wave equation migrated image of the Coso geothermal field.
4. Determine the validity and accuracy of seismic imaging by comparison to drilling data, other geological/geophysical information, and prior processing results.

Actual Outcomes:

1. The researcher made minor modifications to the algorithms to read and to fully utilize the Coso geothermal field seismic imaging data.
2. The researcher implemented a near-surface velocity model using first-arrivals from the seismic data and turning ray tomography inversion. This implementation removed near surface distortions.
3. The researcher generated high-resolution wave equation migrated images of the Coso geothermal field using each of the following methods: a) 3DGeo's ComAz wave-equation migration algorithm, b) pre-stack time migration, c) post stack time migration, and d) pre-stack Kirchhoff depth migration.

4. The researcher compared the images to prior existing images, published geological and geophysical information, and analyses. The project compared the velocity models to results previously obtained by other workers. The project validated the new high-resolution images against the known geology.

Conclusions:

1. This project has taken the first step in validating the application of 3DGeo's proprietary seismic imaging technology to a California geothermal data set.
2. Geothermal areas generally produce challenging seismic data that push the limits of processing and imaging technology. This project has demonstrated the challenges can be overcome through the proper application of state-of-the-art seismic imaging technology.
3. Active source reflection seismology appears to offer benefits to geothermal exploration and development. High quality seismic data processing is important to obtain accurate and usable imaging results. The quality processing is not limited to the high-end imaging algorithms such as Kirchhoff migration, but also is valuable in the preprocessing applied to data. Statics and pre-stack noise attenuation appear to be important to obtain a good imaging result.
4. The images generated in this project appear to support the proposed methodology for processing geothermal field seismic data. The major goal of this study was to demonstrate that seismic imaging of structures could be obtained in heterogeneous geothermal environments. Therefore, the researcher assessed the success of the experiment by reference to the seismic imaging results themselves and the fact that knowledgeable geophysicists could identify known geologic structure from the images. While interpreting the images remains an art, there does appear to be more details in the new images that have a positive correlation to the known geology.

Benefits to California:

Because this technology can lower the cost of finding and producing geothermal energy the electric ratepayer will receive economic and environmental benefits. The California Legislature recently passed SB1078 that mandates utilities to provide 20% of their electricity from renewable resources by 2017. Technologies such as the one demonstrated in this grant will both lower the cost of developing the required resources, and also may lead to discovery of more geothermal resources within the State. The increased utilization of California's renewable geothermal resources will benefit the State as a whole by reducing the need to import and consume increasingly costly conventional fuels. Reduced consumption of fossil fuel will also improve California’s air quality.

Recommendations:

The PA recommends further processing of the remaining Coso data. Researchers should acquire another 2-D or preferably 3-D survey in Coso or elsewhere for further imaging and demonstration of the technology in a larger more in-depth effort. Further development of this technology through a large-scale demonstration will clarify its capability by giving an example of its full potential.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Completed.

Modeling Greenhouse Temperature for Energy Efficient Production

EISG Grant Number: 99-08
PIER Area: Industrial/ Ag/ Water
Principal Investigator: Heinrich Lieth (530) 752-7189
Organization: University of California, Davis
Grant Amount: $75,000
Status: Completed

Project Description:
California is the leading state in the US floriculture industry, with wholesale value over 700 million dollars per year. With more than 115 million ft2 area under greenhouse cover, California has the largest area of protected crop production facilities in the nation [National Agricultural Statistics Service, USDA. 1998].

Greenhouse agriculture requires considerable energy for cooling in the summer and heating in the winter. While computers have been incorporated into most greenhouses, no significant environmental control software exists. Each crop that might be grown in a greenhouse has different temperature requirements. Proper use of an accurate crop model embedded within greenhouse environmental control software will enable achievement of the optimum energy efficiency for the greenhouse crop combination.

Proposed Outcomes:
The goal of this project was to determine the feasibility of embedding a sufficiently detailed and accurate model within the greenhouse environment control software to enable optimum energy efficiency for the greenhouse crop combination. The researchers established the following project objectives:

1. Create and integrate greenhouse climate models with crop models.
2. Validate the integrated model.
3. Develop general-purpose energy management software tools that growers could use to assist in greenhouse energy management.

Actual Outcomes:

1. A full-sized, large-scale simulation model was developed that simulates the greenhouse climate in relation to the control objectives, the outside climate, the crop growing in the greenhouse, and the various management practices. This model was then implemented on a computer simulation system. The size and complexity of the model was such that the high-end computer workstation it was hosted on would only simulate short time frames. The researcher could not fully exercise the computer model due the excessive memory demands of the program, even when running on a high capacity workstation. Evaluation of this implementation was not completed.
2. Partial validation of the model was performed. The simulation model behavior was satisfactory in most areas except for its inability to accurately predict the air temperature and humidity inside the greenhouse in the winter.
3. A software tool was developed that allows growers to calculate temperature set points in relation to rose-crop development for cut-flower roses. Presentations and training sessions at national grower meetings (March 30, 2001 Denver, Colorado) have been conducted to assist growers in using the software. The software tool was made available to the public through publication on the web to allow easy access by the greenhouse

operators. The Principal Investigator has indicated that this software tool has been downloaded for use by rose growers in California.

Conclusions:

1. Considerable insight was gained into the many variables that impact greenhouse thermal properties. The complexity of the modeling and simulation was greater than originally anticipated. The size and complexity of the model and its inability to run effectively, even on a high end computer workstation, makes the model impractical for real time greenhouse control in its current configuration. The accuracy of the integrated model was impacted by errors contained in existing models/data.
2. Further work is needed to validate and optimize the model for accuracy before it can be used for comprehensive energy simulations. Feasibility of integrated greenhouse climate models with crop models has yet to be established.
3. Due to the complexity of the various crop models it may not be possible to create general purpose energy management software tools that could be applied to a variety of crops. Instead, it appears that the software tools will need to be tailored to specific crops, which will require considerable research and development.

Benefits to California:

Greenhouse growers will benefit directly from the tool that was developed as part of objective 3 of this project. The tool is particularly targeted to cut-flower rose growers, to assist them in selecting temperature set-points that will allow them to schedule crop maturation to coincide with holiday sales. This tool allows growers to maximize profitability by optimizing productivity through precise energy management. Energy use by cut flower growers may be reduced by use of this energy control tool.

Recommendations:

The simulation system, as an analytical tool, will require considerably more work before it will result in widespread practical applications for greenhouse energy management. Additional work is needed that would allow the model to run effectively on a standard computer. The model needs additional development to make it more accurate in the areas of noted deficiency. Specific crop models need to be developed that can be integrated into the greenhouse climate model.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Non-Vacuum Thin-Film Photovoltaics Processes

EISG Grant Number: 99-31
PIER Area: Renewables
Principal Investigator: Chris Eberspacher (805) 987-7258
Organization: Unisun
Grant Amount: $75,000
Status: Completed

Project Description:
Photovoltaics (PV) is a small but rapidly growing sector of California's electrical power generation capacity. For PV to significantly impact the State's economy and quality of life, the cost of PV-generated power must decrease. One of the most promising strategies for lowering PV costs is the use of technologies in which thin films of materials are deposited on inexpensive substrates like window glass. One of the most promising thin- film materials is copper indium gallium selenide (CuIn1-xGaxSe2 or CIGS).

Vacuum deposition processes have difficulty depositing CIGS films on large areas with the precision and control necessary to achieve low manufacturing costs. Non-vacuum deposition techniques provide a simple, low-cost alternative. Preparing fine powders of precursor materials, depositing thin layers of the particulate precursor materials, and sintering the layers into high-quality dense films can form high quality thin films.

Simple, non- vacuum techniques such as spraying and printing can deposit layers of particles on large-area substrates. Exploratory materials research using simple pneumatic spraying yielded cells with 11.7% efficiencies and monolithic multi-cell modules with 5% efficiencies. However, the sprayed layers were not very planar (i.e. flat) and were not very well packed (i.e. dense), and deposition rates and materials use efficiency were low. The aim of this EISG project was to deposit uniform, planar, well-packed layers with high materials use efficiency (MUE).

Proposed Outcomes:
The goal of this project was to determine the feasibility of depositing planar, well-packed particulate layers at high rates with high materials use efficiency (MUE) using non-vacuum techniques. The researcher established the following project objectives:

1. Identify high-MUE, non-vacuum deposition techniques and obtain suitable equipment for experimental evaluation.
2. Develop high-MUE spraying techniques using CIGS precursor materials.
3. Fabricate efficient thin-film PV devices using high-MUE techniques.

Actual Outcomes:

1. The researcher identified high-MUE, non-vacuum deposition techniques and procured suitable equipment for experimental evaluation.
    - Pneumatic spraying resulted in good atomization and excellent spray directionality, but materials use efficiency was low.
    - Without gas assistance, ultrasonic spraying resulted in good atomization, but the lack of carrier gas resulted in poor spray directionality.
    - Gas-assisted ultrasonic spraying yielded good atomization and good spray directionality.
    - Electrostatic spraying at 30 kV yielded relative materials use efficiency gains of 50-65%, but the deposition pattern was erratic and irreproducible.

- Casting and spray casting yielded high materials use efficiencies and well-packed, planar layers.

2. The researcher developed high-MUE deposition techniques for depositing layers of CIGS precursor particulate materials.
   - The morphology of particle layers deposited by pneumatic spraying varied with spraying conditions.
   - Layers sprayed in a manner that facilitated rapid local solvent evaporation exhibited microscopically planar surfaces.
   - Layers sprayed using slow solvent evaporation conditions exhibited non-planar surfaces characterized by a network of ridges and valleys.
   - Droplet drying mechanisms resulted in observed morphological variations.
   - Individual droplets of well-dispersed, well-suspended slurry dried to form rings of particles.
   - Networks of ridges and valleys evolved as particles were differentially collected into ridges by the interplay of ring overlap, particle bounce-back, high-angle over spray, and particle/gas lateral flow.
   - Spray conditions that facilitate rapid solvent drying mitigated local drying effects that cause non-planar layer morphologies but such conditions reduced materials use efficiency.
   - Ultrasonic spraying minimized particle loss mechanisms and yielded higher materials use efficiencies, however, ultrasonic spray deposition resulted in non-planar layers characterized by ridges, valleys, and small agglomerates.
   - Spraying under conditions that mitigate in- flight droplet drying sharply reduced the density of small agglomerates but slow-evaporation conditions aggravated the tendency to form a ridges and valleys topology.
   - Casting techniques, which use a continuous "wet film" of slurry rather than isolated droplets, circumvented the non-planar morphologies that result from cycles of wetting and drying.
   - The substrate-wide drying front inherent to solvent evaporation from continuous wet films minimized the formation of ridges and valleys.
3. The researcher fabricated thin-film PV devices using particulate precursor materials deposited using high-MUE techniques, achieving cell efficiencies of 9.4%.

Conclusions:

1. The results demonstrate high-MUE deposition processes can yield PV devices with the efficiencies needed to fabricate commercially viable products.
2. Cost-effective formation of high-quality PV films using particle-based, non-vacuum processes requires the deposition of reasonably planar, well-packed layers of particulate precursor materials with high materials use efficiencies.
3. Non-vacuum spraying techniques provide the necessary combination of planar, well packed layers and efficient materials use provided one mitigates nozzle-related agglomeration, avoids repeated wetting/drying that can cause non-planar morphologies, and facilitates particle rearrangement that can increase packing densities. The demonstration of efficient spray deposition of planar, well-packed layers lays the foundation for the fabrication of efficient, large-area, thin-film PV modules using non-vacuum processes.

4. Since the techniques developed in this project can yield higher particle packing densities in particulate precursor layers, improvements to final film quality can accrue from adjustments to the reactive sintering processes used to convert porous precursor layers into dense final films.

Benefits to California:
If this line of research reaches a successful conclusion, California will benefit in several ways. Rooftops equipped with solar power systems provide customers the option of generating their own clean, quiet, reliable electricity. Solar power, with its ability to provide electricity at home or at a business site, can help offset the need to purchase electricity and increase consumer autonomy. PV technologies based on thin films can potentially deliver the end- user price reductions necessary to expand the use of PV significantly and aid California ratepayers in realizing a pollution-free, renewable energy option.

Recommendations:
The techniques developed in this project yield efficient small-area solar cells. Further research is needed to test these techniques in the fabrication of larger-area, monolithically integrated, multi-cell modules suitable for commercial production. The next steps are:

- Investigate synergies that might arise from combining improved particle layer deposition techniques with improvements to the layer-to-film sintering processes.
- Apply the high-MUE particulate layer deposition techniques to the fabrication of large area, multi-cell modules.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Novel Composite Membranes for Fuel Cells

EISG Grant Number: 99-19
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Sossina Haile (626) 395-2958
Organization: California Institute of Technology
Grant Amount: $74,942
Status: Completed

Project Description:
Fuel cells utilizing a polymer electrolyte membrane (PEM) have the desirable characteristics that they operate at near room temperature with high power density. A less desirable characteristic of the proton-conducting polymer is that it utilizes water, in the form of the hydronium ions, H3O+, as the proton conductor. This leads to a requirement for water re-circulation and temperature control in the system. In addition, the need to maintain hydration limits the maximum allowable temperature and results in low efficiency in hydrogen-air fuel cells. PEM fuel cell operating at higher temperatures can demonstrate improved efficiency and reduced carbon monoxide poisoning of the catalyst.

If a substitute for the hydrous component in the fuel cell membrane were found, manufacturers could eliminate the need for water re-circulation, relieve thermal management issues and achieve the benefits of higher temperature operation's increase of catalyst efficiency in generating protons at the fuel cell anodes. This benefit is directly applicable to all PEM fuel cells including hydrogen/air fuel cells, and cells fueled by reformed hydrocarbons. These fuel cells are typical of those applied to power generation.

Many solid acids exhibit excellent proton transport properties, but less than ideal mechanical properties and chemical stability. For these reasons, the researcher selected and investigated composite materials utilizing an inert polymer matrix to support the embedded solid acid.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using proton-conducting membranes that do not rely on hydrated polymer for proton transport in a PEM fuel cell. The proposed membranes are composites of inert polymers and "solid acids." The following project objectives were established:

1. Prepare, characterize and evaluate a broad range of polymer/solid acid composite membranes for subsequent development of membrane electrode assemblies.
2. Fabricate and Characterize electrodes and membrane-electrode assemblies. Understand and optimize electrode microstructure.
3. Demonstrate a single cell fuel cell utilizing a sold acid based membrane operating at temperatures between 100 and 180^{o}C.

Actual Outcomes:

1. A large number of composite membrane systems (more than 12) were prepared, characterized and evaluated. The majority of these systems exhibited low conductivities and poor homogeneity, although some, notably composites formed using a ceramic matrix, had conductivities within an order of magnitude of the solid acid alone and excellent reproducibility. Because of the higher conductivity of the solid acid alone, such membranes (in which the inert matrix material was eliminated) were used for further fuel cell development.

2. Membrane electrode assemblies were fabricated using various techniques. The most successful technique discovered was the simultaneous cold-pressing of the electrode/electrolyte/catalyst layers and the electrolyte membrane material. A volatile organic (naphthalene) was added to assure porosity. These assemblies were very thick because of the need to assure impermeability of the solid acid layer.
3. Fuel cells were demonstrated using several variations of electrode/electrolyte/catalyst layers. They can be generally characterized as exhibiting an open circuit voltage ranging from 1 to 1.12 volts, and producing power ranging up to 12 mW/cm2.
4. An unanticipated outcome of this research was the discovery that in a reducing environment (flowing hydrogen) the sulfur content in the solid acid reduced to H2S. The rate of conversion was higher in the presence of a metal catalyst. This chemical reaction limits the long-term stability of these fuel cells. Solid acids not containing sulfur were shown to be stable, but as of yet no solid acid combining high stability and high conductivity have been identified.

Conclusions:
Knowledge was gained and conclusions were drawn from each step in the progress of this project as detailed in Appendix A. The researcher summarized the project in these words
"The problem of sulfur (or selenium) reduction has proved vexing indeed. The development of optimized membrane electrode assembly structures awaits the discovery of alternative solid acids with greater chemical stability (materials that exclude sulfur and selenium)." This project determined that the use of proton conducting membranes that do not rely on hydrated polymers for proton transport in PEM fuel cells is not feasible using *current* solid acid materials.

Benefits to California:
In this project it was demonstrated that the path to a successful energy product that will benefit California electric ratepayers requires as its first step the development of alternative solid acid materials. It cannot be predicted at the outset whether such materials will be discovered.

Recommendations:
The basic thesis for this project was sound and the research was carried out in a professional and competent manner. Unfortunately the chemistry involved did not result in a usable anhydrous membrane material. If one is to realize the potential advantages of anhydrous, thermally stable proton conductors, “alternate solid acids with greater chemical stability" must first be discovered.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

EISG Projects Completed in 2002

Anaerobic Pump

EISG Grant Number: 99-38
PIER Area: Renewables
Principal Investigator: Keith Schimel (315) 425-7741
Organization: Technology Matrix Corporation
Grant Amount: $71,000
Status: Completed

Project Description:
Anaerobic digestion, as it is currently practiced, is limited in application because incomplete biochemical reactions severely limit the extent of the biological production of methane. This limitation is mainly due to the resistance to decomposition of many complex solid organic substances that constitute wet biomass.

In 1980, Dr. Keith A. Schimel invented a new continuous flow, continuous culture anaerobic process which was shown to nearly complete the digestion of wet biomass solids with an ordinary mixed culture of anaerobes. The design concept of this process is based on using the product biogas to plasticize the residual solids. In these early tests, development was focused on solids reduction and doubling the normal digestion speed of raw waste activated sludge. The data showed as much as 90% volatile solids (Organic materials) reduction and 80% chemical oxygen demand reduction could be achieved if the process is operating at optimum.

In the current project the focus was to validate the high solids reduction and improve the process's biogas (primarily methane) production. Methane produced by this process can be used to fuel electricity power plants in California. If deployed the technology could not only play an important role in the reduction of wet biomass solids, it could also provide a significant amount of fuel gas (methane) for power plants.

The project compared the methane production performance of this advanced hydrolysis and biogasification process with a conventional digestion process. Two prototype reactor systems were implemented. The advanced hydrolysis and biogasification process and a conventional, single-stage, "completely mixed by stirring" (CSTR) digester were operated side by side under identical conditions. Both systems were fed the same substrate, a 50:50 mixture of wastewater sludge at the same loading rates. This substrate is commonly used as a test substrate because it is widely available and is difficult to degrade. Both systems were held at the same low incubation temperature (20^{o}C) so that accurate observations could be made.

Proposed Outcomes:
The goal of this project was to determine the feasibility of using the advanced hydrolysis and biogasification process for significant production of power plant fuel (biogas) by the reduction of wet biomass solids. The performance of the prototype reactor system implementing the advanced hydrolysis and biogasification process was compared with the performance of the CSTR reactor, the conventional technology used to reduce wet biomass solids. The following project objectives were established:

1. Peak specific gas production rate higher than the CSTR by a factor of 3.
2. Peak Methane production rate higher than the CSTR by a factor of 4.
3. Methane yield in liters per kg volatile solids twice that of the CSTR.
4. Total volatile solids reduction three times higher than the CSTR.
5. Total volatile Chemical Oxygen Demand Reduction three times better than the CSTR.

Actual Outcomes:
This prototype reactor system implementing the advanced process had the following measurable outcomes:

1. The specific gas production rate is 3.3 times higher than that for the CSTR.
2. The peak methane production rate is 3.9 times higher than that for the CSTR.
3. The methane yield in liters per kg volatile solids added is 1.88 higher than the CSTR.
4. The volatile solids reduction is 2.35 times more than for the CSTR.
5. The total Chemical Oxygen Demand Reduction is 3.35 better than for the CSTR.

Conclusions:
These results were developed by comparing the results of the tests of the two prototype units of identical volume, operated side by side at 20 degrees Centigrade. The Outcomes show that the prototype reactor system implementing the advanced process produces 1.88 times more methane per unit mass fed than the CSTR. All other figures of merit are also superior to those of the CSTR.

These results verify the feasibility of using the advanced hydrolysis and biogasification process for methane production thereby increasing wet biomass solids reduction. Overall, the advanced hydrolysis and biogasification process can convert organic solids to methane between two (2) and four (4) times faster (depending on loading) than a comparable CSTR unit. Most importantly, the total volatile solids reduction was 2.35 times more complete on the advanced hydrolysis and biogasification process than with CSTR. While this is less than the goal of three times improvement, it is nonetheless a significant improvement, because with the advanced hydrolysis and biogasification process nearly all the biomass feedstock is convertible to biogas (primarily methane), leaving little solid material for disposal.

It is important to note that while this experiment was performed at 20^{o}C in order to slow the reaction for purposes of comparison between the advanced hydrolysis and biogasification process and CSTR, the optimal operating temperature for the mesophilic range is 35^{o}C. The standard rule of thumb is that the reaction rates for these digesters would be about 2.5 times faster if operated at 35^{o}C rather than at 20^{o}C.

Benefits to California:
All large power plants being proposed for California rely on natural gas as the fuel. Most of that fuel is imported into the state. Biogas (predominately methane) can be produced from indigenous biomass material. The major sources of wet biomass waste produced in California are sewage sludge production, fiber production (pulp and paper), food processing, agriculture and animal wastes. These sources could generate over 45 million tons of wet biomass in California. If the advanced hydrolysis and biogasification process were to penetrate 100% of the Wastewater Treatment industry and 20% of the agriculture industry, that process would produce an estimated 1.54 billion therms of biogas (methane) gas per year for electrical generation or for process heat. Because of the existing capital investments in waste treatment, benefits would build over a period of 10 to 15 years. It is likely that investors would first build treatment facilities utilizing the advanced hydrolysis and biogasification process to handle concentrated sources of wet biomass waste. Once scrubbed of impurities, the biogas could be directly used in power plants.

In addition, the deployment of this process would reduce the environmental problems and expense associated with the disposal of large volumes of wet biomass solids.

Recommendations:
The testing completed on this project has assisted in identifying areas where additional development is needed. Areas for additional effort are:

- Demonstrate a commercial scale (sized 1 to 4 ton/day) agricultural prototype, and select a strategic partner to help with commercialization. Seriously evaluate the benefits of designing this prototype to be highway truck transportable.
- Evaluate methane production from new feed stocks to expand applications for the advanced hydrolysis and biogasification process.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Control of On-Off Equipment in Buildings

EISG Grant Number: 99-03
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: David Auslander (510) 642-4930
Organization: University of California, Berkeley
Grant Amount: $75,000
Status: Completed

Project Description:
Equipment used to control process variables such as temperature in buildings often operate by cycling on and off (or between stages if more than one "on" state) rather than as continuously modulating. Examples of such equipment include small to mid-sized packaged air-conditioning systems, furnaces, chillers operating at low loads, cooling tower fans, and some types of electrical heaters. On-off control units normally start and stop equipment when the process variable (e.g., space temperature) crosses a level. There are a number of disadvantages to using level-crossing logic. One disadvantage is that it is difficult to control the variation in the process variable with level-crossing logic, even if it is implemented digitally, because of the phase lag of the process. Another disadvantage is that level-crossing logic is not well suited for staged operation in which there exists more than one "on" state. A third disadvantage of level-crossing logic is that it makes the coordination of multiple units difficult.

This project developed and tested the feasibility of a new control strategy for the operation of "on-off" and staged equipment in buildings using computer simulation methods. Specifically, it developed the control logic so that it could be used to coordinate the operation of multiple units, and compared the performance of the new strategy with level-crossing logic. This technology was proposed as a means of reducing the energy consumption of HVAC equipment by reducing the frequency of start-stop operations. If the hourly start-stop cycling is reduced by two-thirds, the coefficient of performance of vapor compression equipment is raised an estimated 10%. The corresponding improvement for non-electric heating equipment efficiency is estimated at 6%.

This project applied pulse-width modulation (PWM) logic and a finite state machine to start and stop individual units. This control software was combined with a model of the heat transfer dynamics of a building and a transient model of HVAC equipment to study the performance of the new strategy and compare it to alternative strategies.

The metrics used to assess performance were energy consumption, peak demand, thermal comfort, and maintenance cost. The variability of the space temperature was used as a proxy for thermal comfort. Start-stop operations were used as a proxy for maintenance cost.

Proposed Outcomes:
The goal of this project was to determine the feasibility of reducing the energy consumption of HVAC equipment by reducing the frequency of start-stop operations. This was to be achieved by use of a newly developed control logic to coordinate the operation of multiple HVAC sub-systems. The following project objectives were established:

1. Develop new control software for operating energy-intensive, on-off, or staged equipment in buildings by adapting existing concepts for designing pulse-width modulation logic and finite state machines to this application.
2. Perform a computer simulation analysis of the performance of the control software to determine whether or not the new control strategy has energy, thermal comfort, or maintenance benefits relative to existing methods of operating this equipment.

3. Assess the change in energy efficiency as a result of the change in start-stop operations of vapor compression equipment with a target of 13% improvement, and non-electric heating equipment with a target of 6% improvement.
4. Maintain occupant thermal comfort levels.

Actual Outcomes:

1. The control software development yielded code that could be used to operate a wide variety of staged HVAC equipment in buildings.
2. The computer simulations determined that the proposed control logic had no beneficial impact on overall energy consumption, thermal comfort or maintenance costs.
3. The new control logic increased the frequency of start and stop operations by 27%.
5. The new control logic increased the size of the deviation from the space temperature set point by 11%.
6. An unanticipated outcome was the discovery that the new control logic combined with an optimized coordinator could load-level the power consumption of HVAC equipment, reducing excursions by 20% relative to level-crossing logic.

Conclusions:

1. Commercialization would involve control software development. The existing code would have to be adapted to a particular platform, but no hardware would be required as long as there was an existing control communication system in place so that a coordinator running on a networked computer could supervise a number of HVAC control units.
2. Using the proposed metric for equipment efficiency, the 27% increase in frequency of start-stop operations corresponds to an estimated seven percent (7%) decrease in coefficient of performance of vapor compression equipment and a greater than one percent (1%) decrease in non-electric heating equipment efficiency.
3. Equipment manufacturers are sensitive to the increased warranty risks due to increased on-off cycling.
4. Equipment installers may be reluctant to utilize this control logic because weaker temperature and humidity control may result in decreased comfort levels.
5. For commercial businesses with high power consumption the cost of power consumed during peak generation periods is high. Using the software control logic developed by this project to level the demand load during peak periods may save on energy costs associated with exceeding a billing rate threshold but any savings may be offset by increased energy consumption, higher maintenance and lower thermal comfort.

Benefits to California:

This project proposed the benefit of increased HVAC equipment efficiency derived from reduced on-off cycling. It discovered that PWM control strategy did not achieve this desired result. While the feature of load leveling by PWM control is an interesting development of this study, it is unclear to what extent California might benefit from this secondary result.

Recommendations:

Additional work is needed to investigate whether or not it is possible to provide energy benefits from the new strategy and to reduce the maintenance penalty. It is possible that by operating the PWM signals asynchronously and at different frequencies the maintenance penalty could be reduced. Asynchronous operation may also yield additional energy benefits. Asynchronous operation would increase the complexity of the design of the control logic, though not necessarily the complexity of its implementation.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Development of a Unique Gas Generator for a Non-Polluting Power Plant

EISG Grant Number: 99-20
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Roger Anderson (916) 635-1606
Organization: Clean Energy Systems, Inc.
Grant Amount: $74,871
Status: Completed

Project Description:
Clean Energy Systems, Inc. (CES, Sacramento, CA) has defined and is in the process of developing a fossil-fueled, zero-emission power generation system. The key to this system is the combustion of a relatively clean fuel with oxygen in the presence of recycled water in a unique gas generator that directly produces a high-temperature, high-pressure gas composed almost entirely of steam and CO_2. Fuel for the system can come from a variety of fossil or biomass sources so long as it is composed almost entirely of the elements carbon (C), hydrogen (H), and oxygen (O). Oxygen is used to combust the fuel rather than air as in conventional systems thereby eliminating the formation of NO_x and large a volume of noncondensible exhaust gases. The high-energy gases produced by the gas generator drive multistage turbines that, in turn, drive an electrical generator. Exhaust gases from the turbine go to a condenser where gaseous CO_2 is separated from liquid water. Most of the water is recovered, reheated and returned to the gas generator. Gaseous CO_2 leaving the condenser passes to a recovery system where it is conditioned as necessary for use in enhanced oil or coal-bed methane recovery operations, for commercial sales, or for sequestration.

The gas generator is one of two key components in the system and is the focus of this program. CES successfully demonstrated the gas generator in this project. A high temperature steam turbine is the other key component requiring development. It was not the subject of this study. The CES generation system can operate with conventional steam turbines, albeit at reduced thermal efficiency.

Data from this project is being used in the design of a 10 MWe gas generator that will be used in system development testing under a cooperative agreement between CES and the U.S. Department of Energy's National Energy Technology Laboratory (NETL). Lawrence Livermore National Laboratory in Livermore California is the site being proposed for the demonstration of the CES cycle. If this site is chosen, the research will include CO_2 sequestration in abandoned oil wells.

Proposed Outcomes:
The goal of this project was to determine the feasibility of the CES gas generator element operating at commercial power generation conditions. While based on rocket engine technology, the gas generator for commercial power generation must operate on different fuels for longer periods of times. The following project objectives were established:

1. Develop, build and demonstrate a gas generator having a premixing injector element design. Operate the gas generator on pure oxygen and methane adding water for steam production. The methane and oxygen mixture is not used in rocket technology, nor is it used in conventional power generators.
2. Operate the gas generator stably and reliably for extended periods of time. Gas generators of this type typically do not run on methane fuel, nor do they run for extended periods of time.

3. Operate the gas generator at temperatures and pressures required for a power generator. Temperatures and pressures required for commercial power generation differ from those required for rocket propulsion.
4. Demonstrate reliable premixing of oxygen, water and methane. The test must provide a stable flame over long periods of time to achieve the zero emission goal.
5. Demonstrate time-temperature process control in cool-down modules to promote re-association of by-products, thereby creating a clean, two-species gas. To achieve the zero emission goal the gas generator must burn all of the methane fuel while not creating carbon monoxide.

Actual Outcomes:
Significant outcomes of the program and major test results are as follows:

1. A complete gas generator with a premixing injector element was designed, built and successfully operated on oxygen, methane, and de-ionized (D.I.) water. The tests were accomplished at the University of California, Davis campus. This test system is available for further research and demonstrations on other feeds.
2. The gas generator operated repeatedly, reliably, and stably. At the completion of the project it had experienced more than 75 starts with a total run time of more than 10 hours and one individual test duration of 48 minutes.
3. The gas generator operated at temperatures up to 2700°F (1480°C), pressures up to 300 psia (20 atm), and at several fuel-air ratios. These conditions allow the gas generator to generate steam for today's commercial steam turbines and for advanced high efficiency steam turbines.
4. The researchers demonstrated repeatable ignition and stable combustion of premixed oxygen, methane, and water.
5. The product gases from the gas generator are composed almost entirely of two gas species (steam and CO2) with only a minor amount of O2 and a trace of CO. No hydrocarbons or other volatile organic compounds were detected. The concentration of CO in the product gases was found to correlate well with predicted values.

Conclusions:
This project experimentally established the "proof-of-principle" for a novel gas generator component of a new system for producing clean electrical power from fossil fuels. The gas generator, based on rocket engine technology, produces high-energy drive gases that feed into steam turbines. Significant system integration tasks remain. Integration of such a gas generator into a power generation system could provide a viable, economical approach to zero-emission power production from a wide variety of fossil or biomass fuel. Such a system could make the total recovery of CO_2 possible at an affordable cost and in a form suitable for enhanced recovery of oil or coal bed methane or for sequestration. This project demonstrates a technically feasible method for eliminating from power plants both atmospheric pollution and CO_2 which has been implicated in the global warming concern.

Benefits to California:
The project represents the early development of a zero-emission, fossil-fueled power plant using rocket engine derived combustion technology. When commercially viable these power plants will offer a zero emission alternative to fuel cells for clean power generation. If the produced carbon dioxide is used in enhanced oil recovery, California could gain additional proven oil reserves and the associated economic benefits.

Recommendations:
The Program Administrator recommends that California government and environmental agencies support CES in the development of this technology. The next steps are the development of small-scale demonstrators, larger demonstrators, and establishment of a facility for zero emission research. Lawrence Livermore National Laboratory, (LLNL) is currently attempting to secure funding for such a research facility at Livermore, California. That project would demonstrate both the overall zero emission power plant concept and enhanced oil recovery using the CO_2 produced. CO_2 would be sequestered in the process. High temperature steam turbines represent the other technology advancement needed to commercialize the CES power system for widespread, economically attractive power production. At this time there are no high temperature steam turbines commercially available. The technology to build high temperature steam turbines exists in the rocket engine industry. Significant research and development must be accomplished to take that technology and reduce it to commercial products with long life. Research organizations should also fund bench-scale demonstrations using alternative fuels to verify that this technology can be applied to commercial grades of oxygen with virtually any fossil or biomass fuel.

Project Status
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

High Efficiency Single Phase Air Conditioner

EISG Grant Number: 99-39
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Otto Smith (510) 525-9126
Organization: Smith & Sun
Grant Amount: $75,000
Status: Completed

Project Description:
Electric power system overloads often occur during hot summer afternoons when many residential air conditioners are operating. The majority of these air conditioners are powered by single-phase electric motors. Out of concern for power reliability on these hot afternoons, power companies bring on-line their least desirable power supplies. These are the most expensive to operate, the most polluting or oldest generators. These actions are taken to minimize the probability of system degradation or a blackout. The cost to the power company and to society to supply these air conditioners at the peak load time is high, and is often higher than the rate that the customer is currently paying. Also, emissions from the older power plants are usually higher than the newer power plants. The less desirable power plants would be dispatched less frequently if higher efficiency air conditioners were widely deployed in the marketplace at reasonable prices.

One solution is to power the air conditioners with the more efficient three phase motors. The constraint is that most residences and perhaps 40% of all rural areas have only single-phase power available, and it is uneconomic to change these distribution and wiring systems. The compressors are well designed, but the low efficiency single-phase motors on the compressor shafts are much less efficient than three phase motors of the same power rating.

This project demonstrated the feasibility of using a control system that can operate high efficiency three-phase induction motors from single-phase power supplies. These control systems were originally developed for water pumping applications by the researcher in previous, unrelated efforts. These controls are trademarked under the name Enabler™.

The use of such controls on three phase air conditioner motors could reduce the electrical power demanded by residential and small commercial air conditioners by 8 to 10 percent. Air conditioner manufacturers would design all products with three phase motors, adding the control system to those sold to market segments where three phase power is not available.

Proposed Outcomes:
The goal of this project was to determine the feasibility of operating air conditioners with three phase motors efficiently on single-phase power. A test program to measure efficiency was very carefully designed and implemented in order to provide high confidence in the test results. The following project objectives were established:

1. Design, construct and demonstrate a control system specifically for three-phase air conditioner motors enabling them to run using single-phase power.
2. Demonstrate that residential size central air conditioning units, running on three-phase motors that have been modified with a control system to operate on single-phase power, will consume 10% less electrical energy than equivalent air conditioning units running on single-phase motors.

Actual Outcomes:

1. Control systems were designed and constructed to operate two different three-phase motors from single-phase power. One motor was designated a Model 48T motor, the other, a Model 42T motor. The control systems were capable of operating the three-phase motors. As expected, motor performance was improved. With the control installed on the Model 48T motor, the winding current unbalance was reduced to only one percent, compared to 7.4% with the three-phase power supply. Also, the single-phase input to the control had a power factor of 90.8% LEADING, compared to 75.2% lagging with the three-phase power. With the control installed on the Model 42T motor, the winding current unbalance was reduced to 3.2%, compared to an unexpectedly large 13.8% with the three-phase power supply. Still, the single-phase input to the control had a power factor of 88.3% LEADING, compared to 77% lagging with the three-phase power.
2. All of the objectives were achieved for the two sizes of compressors that were tested. A 48,000 BTU/hour compressor and a 42,000 BTU/hour compressor were tested at an independent commercial testing facility by the professional staff as directed by Dr. Smith. Many tests were conducted. The average Energy Efficiency Ratio (EER) for each configuration is tabulated below, the efficiency improvement is presented in the last row:

Motor Configuration	**42,000 BTU/hour Unit**	**48,000 BTU/hour Unit**
Three-Phase powered three-phase motor	10.816 BTU/Watt-hour	12.436 BTU/Watt-hour
Single Phase motor	10.864 BTU/Watt-hour	10.691 BTU/Watt-hour
Enabler™ controlled single phase powered 3-phase motor	11.294 BTU/Watt-hour	11.950 BTU/Watt-hour
Improvement in Single Phase Powered Energy Efficiency	**3.958 %**	**11.776%**

Conclusions:

The feasibility of operating three-phase motors in air conditioners using single-phase power was demonstrated. The motor performance improvement was consistent with that observed in prior development of the controls on larger motors. Without test results from additional like units, it can not be assumed that the savings of nearly 12 % of the electricity use for the 48,000 BTU/HOUR unit with the control system will be realized on all air conditioners of this size. The 42,000 BTU/HOUR unit demonstrated nearly a 4% energy savings. The test results show that the 42T three-phase motor was significantly below average in efficiency. It was less efficient than the single phase motor. The principal investigator concluded that this resulted from low quality in the area of winding current imbalance and suggested that a motor of average quality of this size would have produced greater efficiency gains. Due to the small sample size and variability in motor quality the Program Administrator estimates the energy savings from this invention to be in the 8% to 10% range on average, but additional testing will be needed to confirm this conclusion. The impact of the tested technology on unit efficiency was significantly effected by motor quality. That quality remains an unquantified variable. If the two three-phase motors selected in this study are representative of the range in quality of commercially available three-phase motors this would suggest that the motor manufacturing industry has a quality control problem that also needs addressing.

The ultimate commercial success of the Enabler™ technology will depend on the impact this technology will have on the retail cost of new air conditioners. The researcher reported that his direct cost for the control system components (purchased at retail) was $128 per unit. The researcher projected that the equipment manufacturers could reduce the direct cost of the control system circuitry to $64 per unit if mass-produced. Based on the $64 cost estimate, the Project Administrator projects an increase of about $100 in retail price per unit of the large 48T class of air conditioner. The control circuit for the smaller units, utilizing smaller capacitors, would have a lesser retail price impact. To put this into perspective, the Program Administrator prepared a simple payback analysis. Two electric rates, $0.10 and $0.25 per KWH, were used to span a broad range of retail prices. The 48T motor tested uses electricity at the rate of 4 KW. By using the new control circuit, one could reduce demand by 10% or 400 Watts. It follows that the modified air conditioner would save 400 KWH in 1000 hours and 1000 KWH after 2500 hours of operation. A person with an electric rate of $0.10/KWH will have a simple payback in 2500 hours of operation, while a person with a $0.25/KWH rate will achieve a simple payback in 1000 hours of operation. Depending on the length of the cooling season, payback could occur in one to two cooling seasons. This supports the conclusion that this innovation offers a near term payback to the ratepayer using this control technology with three phase motors.

The researcher asserts that the direct cost of the control system circuitry could be further reduced if the manufacturers of the three-phase motors made some minor design modifications to the motor wiring. While additional research is required to bring this technology to market, air conditioner manufacturers would be able to adopt this new technology without modifying their existing manufacturing tooling.

Benefits to California:
The primary benefit to California will be the availability of higher efficiency (8-10%) air conditioners to electric consumers that are limited to single-phase power. A second major benefit is the reduction in peak loading of the electrical system on hot summer days. Many advantages accrue to the ratepayers from the reduction in peak loads. The relatively near term availability of these benefits is due to the simple, modular nature of the control circuitry, which can be a simple add-on at first, with integration in depth developed as cost cutting measures by the manufacturers.

Recommendations:
The results of this project indicate that significant energy demand reductions can be accomplished in the relatively near term if the tested technology is deployed in California. Because of the limited funds in the grant, the researcher only tested the control system on two air conditioning compressor units. To further this technology, additional testing is needed to assess the energy savings on a full range of commercially available air conditioning units. Research is also needed to fully define the distribution of motor quality to enable a more accurate projection of average efficiency improvement. In addition, the researcher should select a major manufacturer of air-conditioners as a partner in any additional research to insure that the technology development meets all market needs.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Renewable Hydrogen Fuel Production by Microalgal Photosynthesis

EISG Grant Number: 99-06
PIER Area: Renewables
Principal Investigator: Anastasios Melis (510) 642-8166
Organization: University of California, Berkeley
Grant Amount: $75,000
Status: Completed

Project Description:
The ability of unicellular green algae to produce hydrogen (H_2) gas in the presence of sunlight has been recognized by the scientific community as being a possible way to generate hydrogen gas for energy production. Below is a list of important known factors specific to green algal H_2 production.

1. Photosynthesis can operate with a photon conversion efficiency of >80%.
2. Microalgae can produce H_2 photosynthetically with a photon conversion efficiency of >80%.
3. Molecular Oxygen (O_2) acts as a switch by which H_2 production is turned off.
4. Sixty years of research has failed to overcome the incompatibility of simultaneous O_2 and H_2 production by photosynthesis.

Recent work has shown that the absence of Sulfur (S) from the growth medium of the green algae Chlamydomonas reinhardtii (*C reinhardtii*) causes a specific but reversible decline in the rate of oxygenic photosynthesis but does not affect the rate of mitochondrial respiration. The absence of sulfur from the growth medium triggers a metabolic switch, one that selectively and reversibly turns-off photosynthetic O_2 production. In the presence of S, green algae photosynthesize normally (H_2O oxidation, O_2 evolution and biomass accumulation), however, in the absence of S and absence of O_2, photosynthesis in *C. reinhardtii* produces H_2 rather than O_2. Further refinement of this method may lead to full understanding of the green algae hydrogenrelated metabolism and ultimately the generation of H_2 gas for the fuel and chemical industries.

Proposed Outcomes:
The goal of this project was to determine the feasibility doubling the hydrogen production efficiency of *C. reinhardtii* from the level of ~10% of the theoretical maximum to the level of ~20% of the theoretical maximum. The following project objectives were established:

1. Improve the H_2 production by shifting forward the equilibrium of the reversible hydrogenase catalyzed reaction.
2. Design and test cell growth media that accentuate the metabolism of H_2 production.
3. Test the effect of diurnal cycles on starch mobilization and H_2 production.
4. Identify the rate-limiting step in the H_2 production process.

Actual Outcomes:

1. Two approaches were investigated attempting to shift forward the equilibrium of the reversible hydrogenase catalyzed reaction:
   a. The atmospheric air within the photobioreactor was purged with argon to remove dissolved O_2 prior to initiation of H_2 production. Independent measurements have shown that such degassing is sufficient to reduce the O_2 content of the culture to less than 2% of saturation. This purge resulted in almost immediate initiation of H_2 production, while H_2 production by the control culture was delayed for another 10 to 15 hours, hence this approach shifted the reaction forward, reducing the wait time by roughly 10-15% of the hydrogen production cycle length.

   b. The pH balance of the water in the gas collection device was modified with the thesis that the water was saturated with H_2 gas and perhaps contained a significant amount. No detectable increase in the collected amount of H_2 gas was observed.
2. Multiple designs of cell growth media were tested to accentuate the metabolism of H_2 production.
   a. Determined the effects of salinity:
      i. On chlorophyll content and cell viability. Cell density increased then remained constant with moderate levels of salinity.
      ii. On cellular photosynthesis and respiration. Neither photosynthesis nor respiration appeared to be effected by reasonable amounts of salinity.
      iii. On H_2 production. A moderate level of salinity, 10 mM NaCl enhanced the rate and yield of H_2 gas by 30% and 40% respectively over the control.
   b. Determined the effects of ATP biosynthesis uncouplers as follows:
      i. Methylamine-hydrochloride. Over a very narrow range centered on 5 mM Methylamine, H_2 production increased as much as 20-25% over the control.
      ii. Gramicidin. This chemical was not sufficiently soluble to allow investigation of concentrations greater than about 5 micromoles. However, at that level the effect was similar to that of Methylamine, above.
      iii. FCCP. This chemical significantly reduced the production of H_2.
   c. Determined the effect of trace amounts of S; Used 10, 50 and 100 micromoles S samples. The addition of S was observed to delay the onset of H_2 production. However the total production increased with increase of S until the delay of onset became the dominant factor. Culture with 50 micromoles S added produced about 35% greater H_2 yield than produced by the cultures with no S added.
3. The *C reinhardtii* were cyclically deprived of S and supplied with S, for three complete cycles, and the rate of production of H_2 was recorded. The result was that the single culture of *C reinhardtii* produced about three times as much H_2 in three cycles as the control cultures did in a single cycle. This illustrated the capacity of the *C. reinhardtii* to recover from the catabolic effects of H_2 production when S is provided between H_2 production cycles.
4. The rate limiting step in the H_2 production process was identified by Western Blot analysis of the total cell protein extracts from *C reinhardtii*. This showed that the hydrogenase gene is expressed sparingly under S deprivation conditions.
5. In all cases the gas produced by the *C reinhardtii* algae was collected in a tube (upside down burette) filled with water. The gas collected in this manner was reported as hydrogen. Gas chromatographic analysis of the gas collected showed ~90% H_2, ~10% nitrogen with traces of CO_2 and O_2.

Conclusions:

This research indicates that H_2 production rates approaching 20% of theoretical maximum could be achieved by proper combination of the techniques explored in this project.

1. The equilibrium of the reversible hydrogenase catalyzed reaction can be shifted forward.
   a. There is significant benefit, 8 - 12% production improvement to be gained by rapid transition from aerobic to anaerobic environment in the photobioreactor medium, compared to a "natural" transition.
   b. The question of H_2 solubility in water was not definitively answered.
2. H_2 production can be increased by improving the design of the cell growth media.
   a. Moderate levels of salinity of the culture do not adversely affect cell viability and do increase H_2 production by ~40%. However, there may still be room for improvement with further study.

   b. Due to the modest effect and the high cost of ATP biosynthesis inhibitors, their use is not the method of choice for manipulation of H_2 production.
   c. Sulfur titration holds the promise of improving the yield of H_2 production by as much as 35% in this two-stage photosynthesis and H_2 production method. Its utility in a production environment is a concern.
3. It may be possible to extend the production of H_2 by a single culture ad infinitum by alternately supplementing and depriving the culture of its organic sulfur. Three cycles were demonstrated.
4. The sparse expression of the hydrogenase gene within the *C reinhardtii* is responsible for the limited H_2 production. Genetic engineering should be applied to increase the expression of this gene.
5. The technique for removal of nitrogen from the product gas must be identified.
6. It is evident that incremental improvements in the yield of hydrogen production can be accrued upon R&D of the method. However, further improvements need to be achieved to make "hydrogen production by sulfur-deprivation of green algae" a commercial reality.

Benefits to California:
Both small-scale (industrial and commercial) and larger (utility) solar energy conversion plants (photobioreactors) can be envisioned utilizing the Two-Stage Photosynthesis and H_2-Production process. Remote photobioreactors could be installed as modules in arid areas where sunlight is plentiful and alternative uses of land are minimal. Such a process of H_2 gas production would be sustainable, environmentally friendly and economically attractive compared to most other hydrogen production alternatives.

In addition to H_2, a valuable and clean fuel, the Two-Stage Photosynthesis and H_2 -Production process will generate green algal biomass as a significant “Value-Added Bioproduct” that will enhance the economics and competitiveness of the process.

Recommendations:
Further Research and development should address the specific biological and engineering challenges facing commercialization of this technology.

- Further basic research should be done to improve understanding of the cellular metabolism and basic biochemistry that support this process.
- This project demonstrated that hydrogen production of 20% of theoretical is achievable, however, further research should be done to improve the hydrogen production further.
- Preliminary designs for the scale-up of the process should be created, and a preliminary life cycle cost analysis performed. This analysis should compare the cost of producing electricity by this method to the cost of PV. Further, this analysis should compare the cost of producing hydrogen by this method compared to the electrolysis method.

The technology developed in this project will take 8 to 12 years to advance to the state of market readiness.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Ventilation Measurement and Control

EISG Grant Number: 99-02
PIER Area: Buildings End-Use Energy Efficiency
Principal Investigator: Clifford Federspiel (510) 418-3392
Organization: Federspiel Controls
Grant Amount: $74,970
Status: Completed

Project Description:
Cost-effective and accurately-measured airflow rates, especially at outdoor air intake locations, are a recognized difficulty with ventilation controls. Typically, outdoor air intakes have no ductwork either upstream or downstream. The most common configuration is a set of dampers mounted in a large opening of a mixing plenum. This configuration can cause large non-uniformities in the velocity distribution. Existing airflow measurement technology is not effective with non-uniform airflow. Since outdoor airflow rates cannot be measured accurately or cost-effectively, ventilation systems are routinely operated without knowing ventilation rates, and other key airflow variables. The result is wasted energy or compromised air quality, or in some cases both.

The purpose of this project was to develop an energy-efficient, cost-effective, accurate, and maintenance-free flow measurement and control technique for ventilation systems. This program has a specific technical goal: airflow measurement accuracy of ±10% of actual or ±5% of full scale, whichever is greater. This criterion is derived from an addendum to ASHRAE Standard 62.1. Broader goals included a controller design that requires less maintenance than current technology at lower first cost.

The researchers proposed to use torque characteristics of control dampers to measure flow. They theorized that if the position and aerodynamic torque were measured, then it should be possible to deduce the flow rate. The hypothesis is that torque-based flow measurement (TBFM) should be accurate at low velocities if the damper is constructed to induce aerodynamic torque when throttling. The TBFM should also be insensitive to non-uniform flow because the entire surface of the damper blades is used as the sensing means.

Proposed Outcomes:
The goal of this project was to determine the feasibility of the TBFM technique as a cost effective ventilation airflow measurement device with an accuracy of ±10% of actual flow or ±5% of full scale, whichever is greater. The following project objectives were established.

1. Develop a correlation function (mathematical model) that accurately describes the relationship between the position, aerodynamic torque, and air velocity of control dampers.
2. Perform a computer-based sensitivity analysis using the correlation function. Determine whether or not the goal of ±10% of actual flow or ±5% of full scale can be achieved given typical torque and position measurement errors.
3. Design and construct a prototype flow measurement device and test stand based on the results of the modeling and sensitivity analysis.
4. Demonstrate an accuracy in airflow measurement of ±10% of actual flow or ±5% of full scale, whichever is greater.
5. Achieve a cost effective design that requires less maintenance than current technology.
6. Assess the accuracy of TBFM in the presence of flow disturbances.

Actual Outcomes:

1. Existing theories on the torque characteristics of butterfly valves were combined with published experimental results to formulate a model that predicts the torque characteristics of multi-blade control dampers. The development of the correlation function demonstrated that the relationship between position, torque, and airflow has a simplified form that makes calibration of the correlation function relatively simple. The correlation function predicts that the velocity is the product of a function of the position and a function of the torque.
2. The sensitivity analysis predicted that the technical goal could not be achieved when the damper was nearly open, but it should be easily achievable for the most important operating conditions. The most important operating condition is when the damper is about 10% - 20% open because that is the range of conditions for controlling minimum ventilation. Under that condition, the sensitivity analysis predicted that the technical goal could be achieved, and that the torque-based flow measurement should significantly outperform a pitot tube or similar flow measurement technology.
3. A test stand was constructed that used five high-accuracy pitot tubes in a constricted duct as a measurement standard. A prototype flow measurement device with an offset-blade design was constructed. The offset-blade design uses standoffs to make the damper blades rotate about an axis that is displaced by two inches. This design induces torque even when the damper is fully open.
4. The laboratory-scale tests confirmed the results of the sensitivity analysis. The tests showed that when nearly open, the torque was very low even with the offset-blade damper.
5. To provide a more cost effective device, the flow measurement device was designed without pitot tubes. This eliminated the recurring maintenance task of verifying that the air passages are clear of dust.
6. Tests were conducted to assess the ability of the TBFM technology to operate accurately in the presence of a flow disturbance. To simulate a disturbance, a commercially available louver was mounted to the frame of the TBFM prototype and to the frame of the commercially available flow station. These tests illustrated that the TBFM technology is insensitive to the flow disturbance when the damper is less than 70% open. When the TBFM damper is more than 70% open, the flow disturbance has a significant negative impact on the accuracy.

Conclusions:

1. The TBFM technology can outperform conventional flow measurement technology under a wide range of operating conditions. The TBFM technology is more accurate than a pitot tube when the damper is less than 80% open. This project found that the TBFM technology is insensitive to the presence of a significant upstream flow disturbance when the damper is less than 70% open. The accuracy of a commercially available airflow station was strongly affected by the presence of the same upstream disturbance.
2. The fact that the TBFM technology cannot provide accurate measurement of velocity when the damper is nearly open is a problem for a small percentage of applications.
3. One significant obstacle to commercialization of the TBFM technology is that it cannot be used in the retrofit market because of the expense of retrofitting dampers. Some dampers are embedded in HVAC units, and can only be replaced by dismantling the HVAC equipment. The researcher contacted a manager from a leading energy service company (ESCO) to get an opinion on the commercial viability of the TBFM. The manager told the researcher that his company would have no interest in the TBFM technology because of the cost of retrofitting dampers.

4. A significant obstacle to commercialization of the TBFM technology in the new construction market is that it requires substantial change in the way damper devices are designed and manufactured. In order to get the full benefit, the damper design would have to be changed to an offset-blade design with low-friction bearings, which would involve some re-tooling for an equipment manufacturer.

Benefits to California:
If the TBFM technology were widely used, California would benefit from reduced energy consumption, reduced peak demand, and improved productivity and health. Energy consumption and peak demand would be reduced because the technology would prevent over-ventilation and enable demand-controlled ventilation. Fisk and Rosenfeld (1997) estimate that improvements in indoor air quality could save $12 - 43 billion nationally in lost productivity due to health problems in buildings. The developed technology, if implemented could recover some of that lost productivity by providing better ventilation at a lower energy cost. This would be one step toward improved indoor air quality.

Recommendations:
Follow-on development should focus on the design and cost of the damper system so that this technology could be applied to the new construction market. In addition future work should attempt to improve the measurement accuracy when the dampers are nearly open.

The developers of this technology should work closely with potential manufacturers. Before pursuing follow-on technical effort, the developers should achieve positive indications of interest and support for this technology from members of the HVAC industry. Minimum levels of support would include the provision of acceptable end item cost targets and desired technical specifications.

The awardee has presented a number of technical approaches to resolve the implementation difficulties. These could be pursued once the interest of the industry and the market requirement specifications are established.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

EISG Projects Completed in 2001

Electrosynthesis of Device Quality Semiconductor Films

EISG Grant Number: 99-01
PIER Area: Renewables
Principal Investigator: Shalini Menezes (805) 497-2677
Organization: InterPhases Research
Grant amount: $75,000
Status: Active

Project Description:
This project devised a Copper Indium Diselenide (CIS) deposition method that is simpler, less expensive, and more effective than the prevailing methods. The *Electrochemical Molecular Layer Epitaxy* (EMLE) method was developed in order to simplify the synthesis of electronic grade CIS films and reduce fabrication costs for large photovoltaic (PV) modules. The project targeted the energy problem of reducing the capital equipment cost for photovoltaic (PV) modules production in order to make the cost of PV power systems competitive for California ratepayers. It developed this new non-vacuum approach to fabricate high quality thin-film materials for PV modules that could lower the manufacturing costs by over 50% and increase the PV module efficiencies.

The project addressed the PIER subject area of Renewable Energy Technologies. Within that field, this project addresses the cost of manufacturing solar photovoltaic (PV) systems. Worldwide PV markets have been expanding, with sales projected to exceed $12 billion by 2010. PV could provide a large portion of the state's electricity needs without negative impact to the environment, but this potential is limited due to the high initial cost of PV systems. In order to mitigate costs, subsidized buy-down programs have been introduced so that PV power can compete in the current energy market.

This EISG project explored a means to manufacture PV devices at lower cost. It created a nonvacuum fabrication method, specifically targeting the commercially important Copper Indium Diselenide (CIS) PV cell. CIS technology is important because when fabricated with complex, expensive laboratory scale vacuum methods, CIS cells are more reliable and efficient relative to other thin film PV types. Unfortunately, currently existing low-cost non-vacuum methods, suitable for large-area cell manufacturing result in low-grade films, which require further costintensive vapor phase treatments. The *Electrochemical Molecular Layer Epitaxy* method integrates the low-cost, large area features of electrodeposition with the atomic level, or nanoscale control of vapor phase epitaxial methods to produce high quality CIS films at ambient conditions from aqueous solutions. The project impacts both the positively doped CIS (*p*-CIS) state of the art solar cell, as well as the new flexible, lower cost negatively doped CIS (*n*-CIS) solar cell being developed.

Proposed Outcomes:
1. Design, assemble and test new apparatus and control software for nanoscale-controlled electrodeposition that eliminates need for vacuum processing.
2. Identify critical deposition parameters.
3. Synthesize binary precursor films.
4. Analyze the thin-films with electrochemical and surface analytical characterization.
5. Extend the investigation to produce ternary CIS absorber layer.
6. Begin a process of commercial readiness.

Actual Outcomes:

1. A new non-vacuum electrodeposition apparatus, including process control software, was successfully designed, assembled and tested. The introduction of an unconventional thin layer flow cell was the key element that facilitated a precise electrodeposition process.
2. The effects of the standard EMLE deposition parameters of temperature, electrolyte composition, deposition potential, and timing parameters were identified, along with the effect of electrolyte volume.
3. The CuSe superlattice films (binary precursor films) were grown using three different methods, which enabled the identification of the process parameters.
4. A series of samples comprising 500-800 layers deposited on Mo/glass were analyzed and their composition determined. Film composition was tabulated as a function of the process parameter values.
5. This project led to a new method to produce a commercially valuable ternary CIS film, CuInSe2. The results offer valuable insights into the role of process parameters allowing the identification of a new means to incorporate less noble metals in CIS film as required for high efficiency PV cells.
7. A US Patent was granted on May 8, 2001, based on the concepts underlying the new method.

Conclusions:

While a fully functioning production line is still five years away, this project advanced the science toward using non-vacuum, electro-deposition for the production of thin film CIS PV cells.

1. The new electrodeposition apparatus and methodology represents an important advancement in electro-deposition process technology. It could allow the substitution of inexpensive electro-deposition hardware for the expensive vacuum deposition processing hardware currently needed to produce CIS thin film PV. Major gains were made in fine control of the electro-deposition process.
2. The new electrodeposition methodology, applied to the task of producing CIS thin film PV, has the potential to eliminate vacuum processing, reduce processing temperature, eliminate the need for multiple electrolytes, and eliminate the need for post annealing step. These potential advantages must be demonstrated in a subsequent development phase.
3. The original objective of this project was to produce a binary precursor film of CuSe using the new EMLE process, however, early success in producing the binary film allowed for the project to be extended to include the successful fabrication of a ternary Cu-In-Se material that constitutes the solar cell absorber layer.
4. Characterization of the fabricated binary and ternary samples confirmed the feasibility of the deposition process to produce high quality layers. This result should support the fabrication of CIS PV films with conversion efficiencies comparable to films produced using the existing expensive process.
5. The results of this research support the conclusion that through the commercialization of the new electrodeposition apparatus and methodology that the fabrication cost of electronic grade CIS films could be reduced by at least 50% for large PV modules.

This EISG project has been timely and instrumental in launching an alternate thin film deposition technology with the potential for lower manufacturing cost. The research team learned how to provide fine control of the electro-deposition process. The EMLE method compares well against other low-cost methods for CIS deposition that are being developed for the current *p*-CIS solar cell, as well as for a new flexible, lower cost *n*-CIS solar-cell. Nearly all other methods need an expensive, hazardous high-temperature selenization second step to produce device quality CIS

films. The results are particularly important for the production of low-cost, high-volume flexible solar cells, based on *n*-CIS technology.

Further, the results of this project include a new process representing entry into the field of nanotechnology. This approach of electrodeposition controlled at the atomic level presents a relatively simple, rapid and inexpensive process to create a broad spectrum of complex semiconductor superlattices, heterostructures and quantum well devices. The new findings and their anticipated contribution to photovoltaics and nanotechnology are very important.

Benefits to California:
The project performed R&D on technology that holds many potential benefits to California electricity ratepayers and the state economy. The project technology has the potential to:

1. Provide California ratepayers with a viable cost-effective PV technology.
2. Realize an affordable, reliable, state-of-the-art, clean and safe renewable energy resource for California residents.
3. Provide a timely cost-effective renewable energy option for distributed generation to California utilities and ensure energy diversity, quality and reliability in the electricity markets.
4. Lead to new in-state jobs and higher tax revenues, thus boosting California's vitality and the overall economy.
5. Provide a new developmental entry into the high potential nanotechnology field.

Recommendations:
The success of the feasibility study warrants further development of the new deposition method to fabricate a complete solar cell. The next stage will advance the project to:

1. Extend the functionality of the design, build and test a prototype deposition apparatus and control system suitable for use in fabrication of a complete *n*-CIS solar cell.
2. Advance the EMLE process to optimize the methodology for depositing all components of n-CIS PV cells.
3. Automate the equipment and process and produce a quantity of *n*-CIS PV cells for operational evaluation and analysis.
4. Because there currently exists a complete infrastructure supporting the manufacture and distribution of the positively doped CIS (*p*-CIS) PV cell, it is also recommended that this project advance the process to synthesize the components of *p*-CIS PV cells.
5. Develop a preliminary production readiness plan to produce commercially viable PV module manufacturing equipment.

The EISG project results provide the bases and the directions for future R&D to fabricate a complete PV device. The method will evolve into an inexpensive, integrated system for large scale manufacturing of efficient PV modules. The scale-up will take advantage of the existing automation and process lines designed for the electroplating industry. The final process will be user-friendly, robust and readily amenable to scale-up for mass production of PV modules.

Project Status:

- 100 % Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Improved Operational Turndown of an Ultra-Low Emission Gas Turbine Combustor

EISG Grant Number: 99-13
PIER Area: Environmentally Preferred Advanced Generation
Principal Investigator: Scott Smith (408) 727-8282
Organization: Alzeta Corporation
Grant Amount: $74,103
Status: Completed

Project Description:
Alzeta Corporation is a manufacturer of industrial burners and combustion systems. Alzeta is developing an advanced low-emissions combustor for use in industrial gas turbines and microturbines. Alzeta's goal is to develop a low emissions combustor that is effective, relatively low cost and can be designed to fit into most existing gas turbine engines. The final report (see Appendix A) details design and testing of Alzeta's Gas Turbine Surface Burner (GTSB). Testing was accomplished at atmospheric conditions and in Honeywell's 75 kilowatt combustor test rig.

In California's changing electricity market, small gas turbine generators may be playing an increasingly important role. These units hold the promise of bringing cheaper, more reliable electricity to California's ratepayers. To reduce harmful air emissions, these units must be equipped with combustors that reduce the oxides of nitrogen to less than 5 ppm. Alzeta's GTSB is being developed to address emissions reduction to these levels without significantly increasing capital equipment costs.

The low-emissions performance of the GTSB derives from its ability to stabilize combustion at low adiabatic flame temperatures where side reactions responsible for NOX formation are thermodynamically less favorable than complete combustion of hydrocarbon fuel. To reduce the adiabatic flame temperature, more air than necessary for complete combustion is premixed with gaseous fuel and directed through the combustor. In the gas turbine industry, this approach is called lean-premixed, dry low-NOX (DLN) combustion. The GTSB differs from existing DLN systems. Its stabilization mechanism removes heat from the combustion reactions by radiant heat transfer resulting in lower NOX formation than attainable by well-stirred premixed combustion with the same amount of excess air.

A potential barrier to commercialization of the GTSB, as with other DLN systems, is the problem of operational turndown. It is difficult for DLN systems to sustain combustion when the power level is reduced from full power to levels as low as 50% power. Increasing the operational turndown of the GTSB requires precise local control of the air-fuel ratio over selected regions of the burner surface. This level of control can be accomplished by partitioning the GTSB into independent segments. Under low fuel-flow conditions, the air-fuel ratio can be maintained in an individual segment while fuel-free air passes through adjoining ones. The number and size of the segments can be adjusted to provide stable combustion over the load range. At full load, the entire GTSB is fired with fuel divided among its segments such that each is operated at the same air-fuel ratio.

Proposed Outcomes:
The goal of this project was to determine the feasibility of a segmented GTSB. Alzeta's strategy is to develop a low emissions gas turbine combustor that is effective, relatively low cost, adaptable to existing engines, and has the flexibility to operate over a broad engine turndown ratio. This project's focus is on increasing the operational turndown ratio of the GTSB while

maintaining low emissions over the load range. Alzeta partitioned the burner into segments to achieve this result. They planned to add a fuel-air mixture to the segments in a sequential manner as engine load increased. To be successful, the segmented GTSB had to meet emissions targets of sub-5 ppm NOX (referenced to 15% O2), sub-10 ppm CO and sub-10 ppm unburned hydrocarbons over the operating range of a micro-turbine engine. The following project objectives were established:

1. Provide three conceptual designs of segmented GTSB. The designs should be differentiated by geometry and number of segments. Create criteria to identify and select the most promising design. Produce design drawings for a GTSB that will fit into the Honeywell 75 kWe combustor test rig.
2. Build and instrument the test combustor. This design objective is important because a segmented GTSB is a new concept and has not been previously designed for testing at gas turbine conditions.
3. Test the segmented GTSB at atmospheric conditions. Measure combustor emissions at six engine-operating conditions from idle to full power. Vary the fuel flow split to the segments at each operating condition to optimize emissions. Measure and record NOX and CO emissions at each operating condition and each segmented fuel flow condition. The objective is to prove the capability of the segmented GTSB to achieve NOX emissions less than 5 ppm at atmospheric pressure over simulated engine operating conditions. This atmospheric pressure test, while less rigorous than Objective 4, provides relatively low cost data to the designers early in the development cycle so that adjustments can be quickly and easily made.
4. Test the segmented GTSB at pressures typical of the Honeywell 75 kilowatt Parallon engine. Measure combustor emissions at six engine-operating conditions from idle to full power. Vary the fuel flow split to the segments at each operating condition to optimize emissions. Measure and record NOX and CO emissions at each engine condition and each segmented fuel flow condition. The Honeywell engine operates at conditions typical of most microturbines. Gas turbine emissions often increase with increasing engine pressures. Testing at simulated engine pressures provides information about the pressure sensitivity of the emissions from a combustor without developing a full engine test.

Actual Outcomes:

1. Three GTSB concepts were evaluated. A two-segment GTSB was selected based on ease of fabrication, control system integration and the effect of internal baffles on air-fuel mixing. Alzeta engineers designed the selected GTSB concept to mate with both the Alzeta test facility and Honeywell's test facility for the Parallon 75 micro-turbine.
2. The GTSB was fabricated. The test GTSB was instrumented with thermocouples and gas sample lines. No unusual problems were encountered.
3. The segmented GTSB was tested at atmospheric conditions at the Alzeta test facility. It was operated stably at six conditions that simulated engine power conditions from idle to full power. The NOX emissions were less than 5 ppm (adjusted to 15% oxygen) and CO emissions were less than 10 ppm. The fuel flow split between the two segments was adjusted at each operating condition to optimize the emissions.
4. The segmented GTSB for the Parallon 75 was fabricated and installed in the pressurized test facility at Honeywell. Testing of the segmented GTSB was accomplished at five of the six planned engines conditions. The selected set points were established in terms of air flow through the GTSB. These points were: 13.6 pounds per hour (pph), 18.5 pph, 24.7 pph, 30.8 pph, 37 pph, and 41.6 pph (full power). The test was halted during the transition to full power test conditions due to a mechanical failure of the GTSB. Alzeta engineers believed that the failure was caused by flashback (the flame-front moved backwards toward the GTSB surface and rapidly burned the air-fuel mixture inside of the

fuel injector). All tests performed up to the full engine operating condition demonstrated NOX below 5 ppm (adjusted to 15% oxygen) and CO less than 10 ppm. Unburned hydrocarbon emissions were undetectable under most conditions. All tests were accomplished using only one segment of the two-segment GTSB. The tests using various fuel splits between segments could not be accomplished after the failure of the test GTSB. Since only one day of testing was available at the Honeywell test facility, retesting could not be accomplished.

Conclusions:
Alzeta's segmented GTSB operated as planned at atmospheric pressure conditions. Alzeta's GTSB is capable of producing sub-5 ppm NOX , sub-10 ppm CO, and near zero unburned hydrocarbons at partial load operating conditions of the Honeywell Parallon 75 micro-turbine. Collected temperature data demonstrate that GTSB combustion performance is consistent with Honeywell's combustor design and can be adapted without changing the materials of construction. Demonstration of the segmented GTSB at full engine load conditions was not accomplished due to component failure.

Subsequent to the completion of this project, Honeywell decided to exit the micro-turbine business. This does not diminish the value of the research conducted during this project. Even though the important technical objective of testing a segmented GTSB at engine pressures is yet to be achieved, this EISG funded project has advanced segmented GTSB technology.

Benefits to California:
Once commercialized, the GTSB may allow low emissions turbine generators to be sited in California at a reasonable cost. Actual engine emissions with the GTSB must meet emission control standards in effect at the time of commercialization. The segmented GTSB appears to provide low emissions over a broader load range than currently available technology. This increases design and operational flexibility for turbine engine manufacturers. Distributed power generation has the potential to reduce peak demand on California's power grid and provide reliable backup power in the face of potential power shortages.

Recommendations:
Successful demonstration of the segmented GTSB at points traversing the startup fuel schedule and over the entire load range at atmospheric conditions could lead to an engine ready design and testing in a micro-turbine or full size turbine. Once the GTSB is installed in an engine, the engine start schedule and control logic will have to be developed to provide low emissions over the load range. Extended demonstration in a test or field engine will provide critical operating data for the commercial GTSB micro-turbine product. Finally, GTSB durability and flashback prevention should be objectives of subsequent research and development. The California Energy Commission awarded Alzeta another development program for this burner concept in March of 2001 and has recently announced its intention to expand this line of research under the Environmentally Preferred Advanced Generation subject area of the PIER Program. The Program Administration endorses these actions.

Project Status:
- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

Process for Converting Sewage Sludge& Municipal Solid Wastes to Clean Fuels

EISG Grant Number: 99-04
PIER Area: Renewables
Principal Investigator: Radon Tolman (760) 967-8494
Organization: Environmental Energy Systems, Inc.
Grant Amount: $75,000
Status: Completed

Project Description:
Most new power plants being installed in California are Gas Turbine Combined Cycle (GTCC) plants that burn increasingly expensive natural gas and fuel oil to produce electricity at up to 60% efficiency. These plants can be installed in less than half the time and at less than half the cost of new coal-fired plants and Integrated Gasification Combined Cycle (IGCC) plants that use cheap dirty fuels, but are less than 42% efficient. A new system is needed to adapt the new plants to cheaper fuels, while maintaining their efficiency and environmental performance.

This project researched the feasibility of a supercritical water gasification (SCWG) process to convert compost made from municipal solid wastes and sewage sludge to clean energetic gases. The expectation is to reduce the fuel costs of GTCC plants and to improve both efficiency and environmental performance of existing steam power plants.

Proposed Outcomes:
1. Determine the feasibility of using SCWG to gasify composted municipal solid waste/sludge, consisting of at least 23 wt% solids, with a minimum 96% conversion of carbon to gas.
2. Verify through visual inspection that no significant erosion, corrosion and deposition occurred inside the bench-scale SCWG system.
3. Assess the feasibility of recycling resulting liquids for "zero effluent" design.
4. Update and validate simplified thermodynamic computer simulation and a life cycle cost models that can be used to predict system performance with various fuels.

Actual Outcomes:
1. Use of SCWG to gasify composted municipal solid waste/sludge is feasible by a wide margin:
   - We produced a pumpable slurry mixture containing 40 wt% solids, exceeding the target goal by 74%.
   - The bench-scale system converted over 98% of the carbon in the slurry to energetic gases and steam, including clean pressurized methane, hydrocarbons and carbon oxides in less than one minute, which is twice as fast as the target time.
2. No noticeable erosion, corrosion or deposition was observed in the test equipment.
3. Total suspended solids in the liquid effluent was less than 10%, supporting the feasibility of recycling liquids for slurry preparation after filtering to provide a "zero effluent" design. No toxic materials were produced that would limit disposal of the residue in a landfill.
4. A thermodynamic computer simulation model and a life cycle cost model were prepared, however, there was insufficient funding in the current project to validate the models over a range of inputs, including the test data. Equilibrium compositions were assumed to be sufficiently close to expected commercial operations to provide preliminary predictions of system performance. Results of the computer simulations included:

- Projected 62% thermal efficiency to electric power for the entire proposed hybrid plant. Projected efficiency for retrofit in an existing steam power plant is 52%.
- Projected capital costs of $1,100/kWh for a new hybrid plant, with projected cost of baseload power generation at $100/MWh.
- Projected capital costs of $500/kWh for retrofit to an existing GTCC plant, with projected cost of baseload power generation at $50/MWh.
- Retrofits for repowering existing Steam plants are competitive with GTCC plants burning natural gas costing $3.00 or more /million Btu.

Conclusions:

1. The test results support the continued investigation of composted municipal waste as an economical fuel source for GTCC and existing steam power plants.
2. We demonstrated that compost made from municipal solid wastes and sewage sludge can be made into a slurry with 40 wt% solids, which significantly increases the range of applications, including the production of valuable byproducts, such as hydrogen. This mixture tended to clog in the ¼" preheater tube which was completely alleviated by changing to 3/8" tubing. This problem is not expected in larger tubes.
3. The project successfully demonstrated that the compost slurry can be used in a SCWG process to produce energetic gases and steam, including approximately 35% gaseous hydrocarbons and hydrogen, the largest fraction being methane. The remaining 65% of the carbon in the feed was converted mainly to CO2 and a small amount of CO. The CO2 can be separated for reduced emissions. It is unknown what effect compost grinding had on residence time for gasification. It is also unknown what impact scaling up the reactor tubes will have on the SCWG process.
5. Sufficient yield data was collected to determine gas composition, perform a carbon balance and perform a preliminary evaluation of recycling liquids after filtering for slurry preparation. While no corrosion, erosion or deposition was observed after running the tests, the tests conducted were not designed to accurately assess those effects over long term testing.
6. Environmentally, based on residence time and projected full scale HRSG tubes, a standard module of 100 HRSG tubes per 25 MW turbine can consume an estimated 170 tons of composted municipal solid waste per day, reducing it to approximately 34 tons of inorganic material.
7. The results of the computer simulation models are encouraging in terms of supporting an economic case for commercialization however, the models still include many assumptions that remain to be validated.

Benefits to California:

This project contributed to the Public Interest Energy Research (PIER) program objective of improving energy cost of California electricity through the use of inexpensive biomass fuels. The project also supports the PIER objective of improving the environmental risk by diverting waste streams away from landfills.

Successful commercialization of SCWG technologies could promote business opportunities in several industries, including process development, waste disposal, electrical generation, pollution control and transportation fuels.

Recommendations:
The next research step is to scale up the critical elements of the SCWG system to eliminate the problems associated with the bench-scale system used in the current project and to conduct a series of tests that more accurately represent anticipated operational conditions. General Atomics in San Diego is currently constructing a scaled up SCWG test rig with full-scale HRSG reactor tubes that would be suitable for answering the outstanding technical questions. The following technical questions need to be answered:

1. Test a full range of slurry concentrations in full size reactor tubes to identify the associated impact on steam and fuel gas production.
2. Identify the optimum level of grinding required (if any) for trouble free gasification in full size reactor tubes.
3. Confirm slurry distribution in a 10-tube inlet manifold for scale-up to a commercial plant.
4. Confirm that the energy balance for SCWG is the same using full size reactor tubes.
5. Evaluate the longer-term potential for corrosion, erosion or deposition.
6. Test condensate for yield and quality and cleaning methods for recycle to slurry preparation.
7. Test ash for beneficial use or land filling.
8. Test mild operating conditions for byproduct yields and quality, including liquid hydrocarbons and carbon.
9. Refine computer models and economic feasibility analyses for retrofit to existing gas turbines and boilers.
10. Collect and test fuel gases for combustibility in existing gas turbines, fuel cells and boilers.

Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.